A Secondary BOOK of BIOLOGY

2. Genetics and Evolution

MICHAEL GABB





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2. Genetics and Evolution

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Consultant's Foreword

In preparing this book we have been able to select from illustrations that have appeared in the magazine *Understanding Science.* These provide lucid, attractive, visual communication which we think appropriate at this level. In addition there are many new illustrations. Where possible, subjects are introduced by, or concluded by, practical and theoretical problem-solving material which provides opportunities for teachers to develop in their pupils an investigatory approach to the subject.

We have attempted to stimulate readers by the challenge of curiosity. Almost all the problem-solving material has been used with classes within the C.S.E. band of the ability spectrum, and their favourable reaction was the main criterion for its inclusion.

C.S.E. Biology is seen by the majority of the Regional Boards not merely as the acquisition of knowledge, but as an opportunity for the use of practical and cognitive skills. The expectation is that assessment procedures which attempt to measure these abilities will have a beneficial 'backwash' effect; they will ensure that teachers whose concern is the development of these skills will be encouraged rather than inhibited by the way in which their product is measured.

One hopes that at least a start has been made on a generation of text books which incorporate this aim.

Leicester, April 1966 J. F. Eggleston.

The first volume in this series of biology books, 1. Common Core, covered the basic biology requirements of the various C.S.E. syllabuses. This, the second volume, deals with an *optional* part of the syllabus and will be followed by further supplementary volumes, namely: 3. Ecology and Applied Biology, 4. Bacteriology and Hygiene.

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M.H.G.

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Contents

1. Cells and their Structure

Malpighi – pioneer of the microscope

MARCELLO Malpighi was born in 1628, the son of a farmer, who lived in Bologna in Italy. At the age of 25 he was granted the degree of Doctor of Medicine at Bologna University. After teaching at Pisa and Messina, he returned to his old university where he carried out many of his studies.

Malpighi was one of the most successful of the scientists who pioneered the use of the microscope. His first major work was concerned with developing William Harvey's ideas on the circulation of the blood. Harvey had suggested that the arteries and veins must somehow be connected in order that blood could flow from one to the other, but he was unable to observe any such links. Malpighi, studying the lung of a frog under a microscope, was able to make out the tiny capillary tubes which perform this function. 'Hence,' he wrote, 'it was clear . . . that the blood flowed away along tortuous vessels and was not poured into spaces, but was always contained within tubules, and that its dispersion is due to the multiple winding of the vessels.'

The microscopist studied a wide variety of subjects. He succeeded in dissecting a silkworm under a microscope, showing that it had a complicated structure just as other animals do. Before this it had been believed that such small creatures had no internal organs at all. He also traced the development of the embryo chick in the egg. The Italian scientist's investigations into the human body have been recorded in the naming of the Malpighian layer (one of the layers of the skin) and the Malpighian bodies in the kidney.

Together with Nehemiah Grew (1628–1711), Malpighi is also considered to be one of the founders of the study of plant anatomy, for he examined in detail the structure and development of many plants. During his last years he held the post of medical adviser to Pope Innocent XII. Malpighi died in 1694.

Cells and tissues

The 'week-end joint'

CLOSE inspection of a joint of meat indicates that the different tissues of which the legs of domestic animals are made differ in colour, texture, density, strength, elasticity and in other ways. The 'meat' consists of muscle tissue, red in colour and fibrous in texture. The fat which surrounds the meat is creamy white in colour and non-fibrous, tending to break off in chunks. Layers of connective tissue separate one tissue – or unit – from another. The 'bones' of the joint consist of visibly distinct tissues – bluish, almost transparent, somewhat rubbery cartilage at the end of the bones near the joints, and solid, white, opaque bone tissue along the shaft of the bones, with a soft red marrow tissue in the centre of the bone. Often long, white, string-like nerve fibres can be seen as well as blood vessels and blood.

Organs such as the liver and the kidneys each have different physical and chemical properties. If thin slices are cut or pieces simply ripped off and such tissues are examined under a microscope, some of the reasons for the differences can be found. The remarkable fact is that all these very different organs are made up of units (called cells). The differences are due to the different types of cells which make up the organs.

Practical Problem

With a spoon handle or something similar gently scrape the inside lining of your mouth. Transfer a little of the milky fluid so obtained onto a glass slide. Add 1 drop of about 1% common salt solution – or water, if you are in a hurry – and examine.

Repeat the exercise but add a drop of the dye methylene blue – about 2% concentration.

What does this tell you about (a) the structure of the lining of your mouth, (b) the reaction of different parts of animal cells to methylene blue?

(See page 10).

Cells and their structure

All living things are made of cells. Apart from the very simplest animals which consist only of one cell, the cells that make up animals work together in groups. They do specialised jobs, carrying out the living processes of the animal. Groups of similar cells which work together are called *tissues*. Different tissues are held together in groups by cementing materials.

There are five main kinds of tissue. These are grouped as *epithelium* (lining and covering tissue), *connective tissue* (tissue which binds the organs together and packs the spaces between them), *skeletal tissue* (e.g. bones), *muscle tissue* and *nerve tissue*. The amount of cementing material between cells varies considerably between different tissues. Generally in epithelia it forms very little of the tissue and the cells are very close together but in connective and skeletal tissues it may form the bulk of the tissue and the cells themselves are wider apart.

Lining and covering cells

An *epithelium* is a sheet of cells. The cells are held together by a small amount of cementing substance. The outer covering of the body (the skin), the lining of the gut and other organs, such as the lungs and blood vessels, and the inner lining of the ducts in glands are examples.

Below most epithelia there is a thin sheet of connective tissue, the *basement membrane*. The free surface (the surface which is not attached to other tissue) of some types of epithelia may often have on it short hair-like structures called cilia (see illustration overleaf).

When the epithelium is several layers of cells thick it is said to be stratified.

The cells of epithelia may serve very different purposes. Those lining the salivary gland, and the glands in the intestine for example, produce the chemicals (enzymes) which digest the food. The cells forming the outer covering of the skin are mainly protective, while those of the lung lining produce the wet mucus in which the oxygen dissolves before passing to the blood.

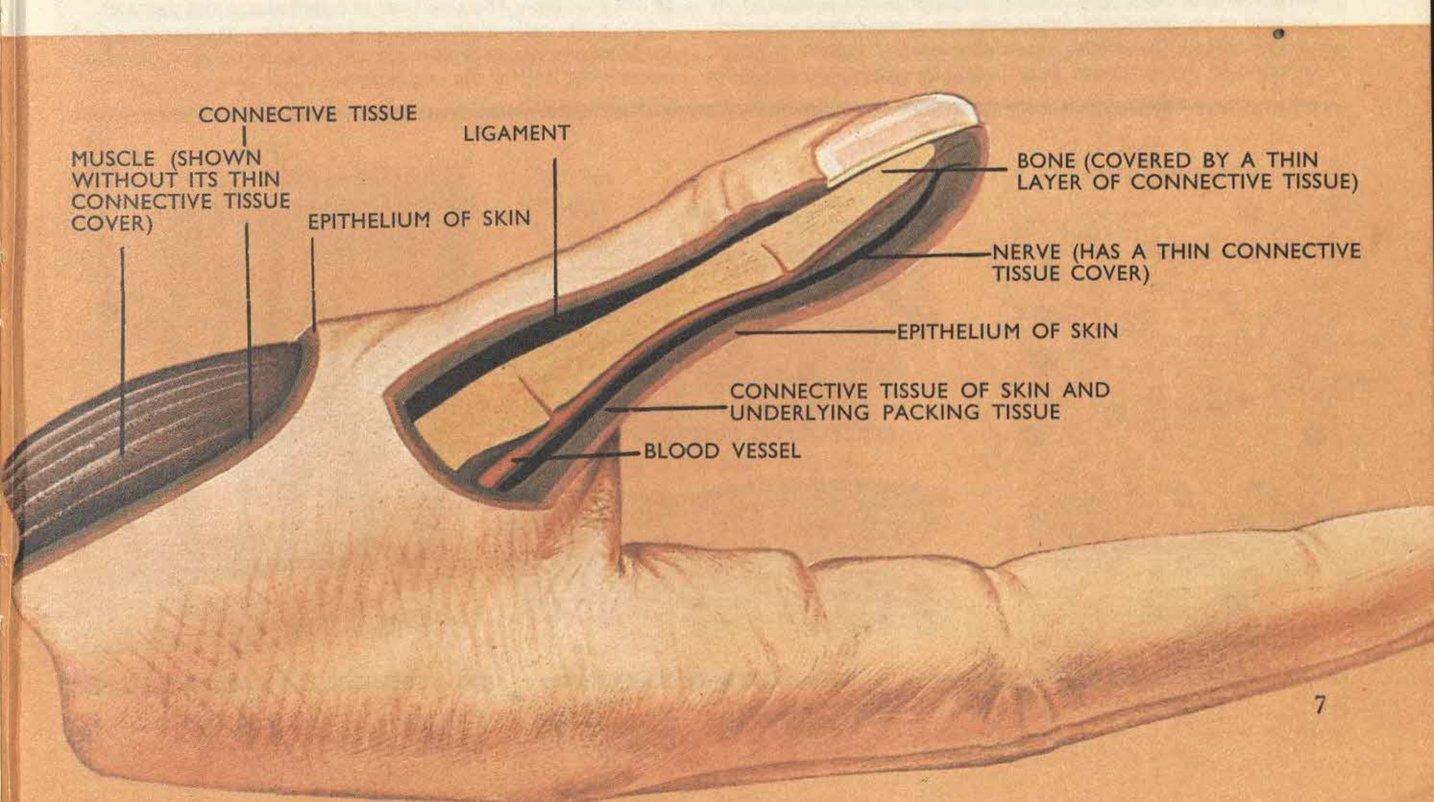
Binding and packing cells

Connective tissue is of importance to the body. It holds the cells of the organs together, supporting and surrounding them and passing on food to them from the blood, binds the parts of the body together, and many of its cells are active in fighting and destroying disease-carrying organisms.

The cells in connective tissue are always well spaced in a base substance or matrix, in which there may also be long, thin threads called fibres.

The most common type of connective tissue is called *areolar* tissue. It forms a layer beneath the lining of the gut and is also a packing material between muscles and other organs. It consists of a jelly-like ground substance in which there are several kinds of cells and interlacing bundles of fibres. The fibres are of two kinds, white and yellow. The white fibres are very resistant to stretching but the yellow fibres can be stretched and are called yellow elastic fibres. Some of the cells are able to eat and destroy germs and so play a valuable part in the body's defensive system against disease.

The human thumb cut away to show diagrammatically the relationships of some of the kinds of tissue.



Structural cells

The *skeletal* tissues are *cartilage* and *bone*. They are often included with connective tissues as they have many similarities, but the ground substance in them is solid whereas in other connective tissue it is fluid.

Cartilage, or gristle as it is more commonly called, is flexible. Its matrix contains very fine fibres and also cavities in which lie living cartilage cells. These produce the matrix which is constantly being renewed. It contains very few blood vessels.

Bone, unlike cartilage, has a very rich blood supply. The hollow cavity running through the centre of the long bones and the spaces in the other bones are filled with a fatty material called bone marrow. It is here that the red blood cells develop.

Muscle cells

Every movement we make is due to the pulling action of our *muscles*. There are three main kinds of muscle tissue: *unstriped* (also called unstriated, smooth or involuntary), *striped* (also called striated or voluntary) and *cardiac* or heart muscle.

Unstriped muscle is muscle over which we generally have no conscious control. Such muscle is found in the walls of the gut and the blood vessels. The size of the pupil of the eye is adjusted by involuntary muscles.

Striped muscle we can control at will. It makes up the bulk of the muscles in the body. Examples are the limb muscles, neck muscles and abdominal muscles.

Unstriped, striped and cardiac muscle is made up of a number of units called *fibres*.

Nerve cells

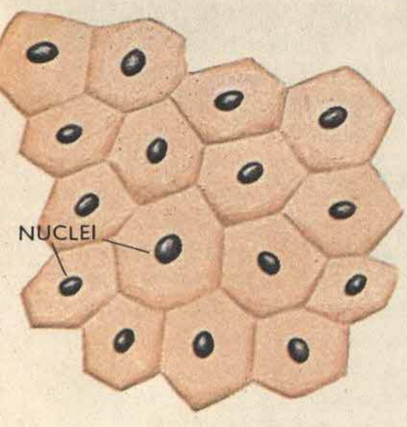
In the simplest animals each cell is sensitive to outside stimuli. Higher animals, however, have specialized regions called receptors which are linked through *nerves* to a central 'switchboard', the brain and spinal cord. Information about the outside world passes from receptors to the brain or spinal cord. There it is transmitted so that the correct organ which is to act (e.g. a muscle) receives a signal through another nerve.

Nerve tissue, then, by passing signals from one part of the body to another, and in some parts storing information, is the body's main controlling agent. Not all the cells in the nerve tissue conduct signals. Some form special types of binding tissue and pass food to the conducting cells.

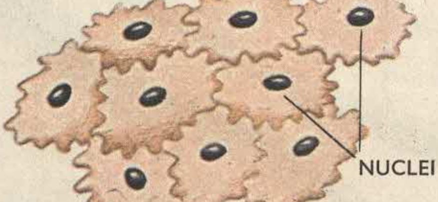
An epithelium may be one or more cells thick and the cells may be of very different shapes and sizes. Some are thin and flat like crazy-paving stones. They form *pavement* or *squamous* epithelium which is found, for example, in the lining of parts of the kidney tubes. When the cells of squamous epithelium have wavy outlines (e.g. cells lining the blood vessels) they are said to be *tesselated*. Other cells are approximately as wide as they are tall. These form *cuboidal* or *cubical* epithelium which is found in many glands (e.g. liver). In *columnar* epithelium the cells are tall and column-shaped. Such epithelium lines most of the gut.

If columnar cells bear cilia the epithelium is then called *ciliated columnar epithelium*. Ciliated cells occur in the lining of the windpipe. The cilia beat to help remove dirt particles.

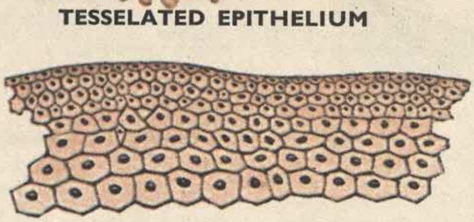
The outer cells of the skin and the lining of the cheek form stratified squamous epithelium. It is also found in the front, transparent layer of the eye (cornea).



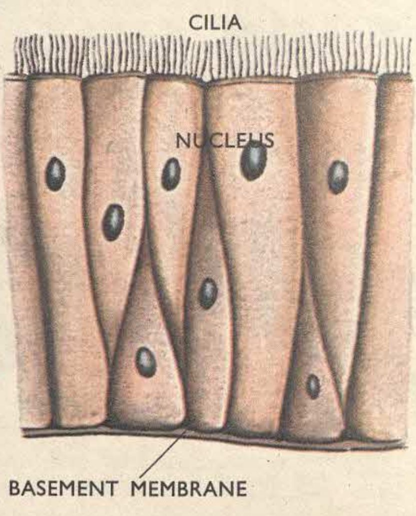
PAVEMENT EPITHELIUM



TESSELATED EPITHELIUM



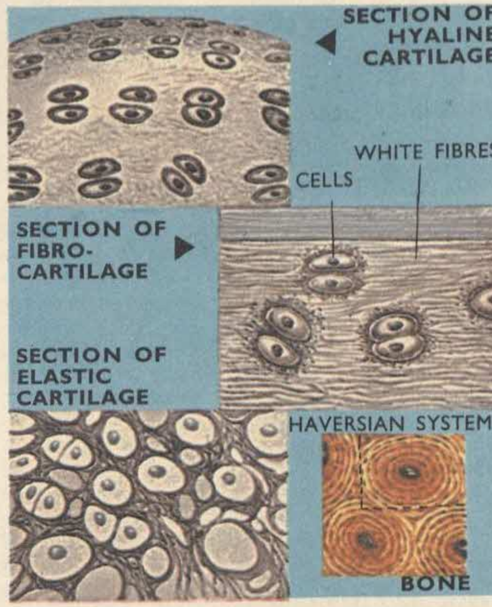
STRATIFIED EPITHELIUM



CILIATED COLUMNAR EPITHELIUM

The simplest type of *cartilage* is *hyaline cartilage* which is transparent, tough and elastic. It joins the ends of the ribs to the breastbone and also covers the ends of bones where these rub together at joints. *Fibro-cartilage* is very tough and contains white fibres, but it is slightly elastic and forms the discs between the bones of the backbone and in the limb joints. *Elastic cartilage* contains yellow elastic fibres and is very flexible. The cartilage in the ear lobes and parts of the larynx or voice-box is elastic cartilage.

A *bone* consists of layer upon layer of hard calcium phosphate and other materials which form the matrix. In this are numerous star-shaped, branching bone cells each of which is in a cavity of similar shape. The cavities are in direct contact with each other through numerous fine canals. Blood vessels and nerves lie in larger canals around which the bone cell cavities are arranged in cylinders. Each canal and its cylinders is called a Haversian system. There are many such systems in each bone.



Some tissues consist almost entirely of white fibres. Examples of this *white fibrous* tissue are tendons, which join muscles to bones, ligaments which bind bones together at joints, and the protective coverings of organs such as muscles.

Yellow elastic tissue is made up mainly of yellow elastic fibres. The ligaments which hold the bones of the backbone together are yellow elastic tissue.

Reticular tissue is a connective tissue which occurs as thin sheets. It surrounds nerve and muscle fibres and also forms the basement membrane of epithelia.

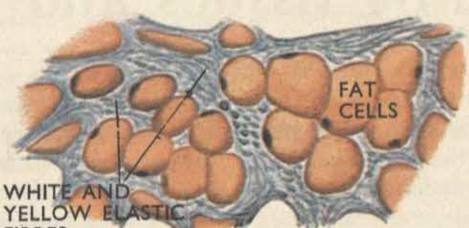
Some connective tissue cells are able to store fat. Such *adipose* tissue is situated mainly in the deep layers of the skin and the mesentery (the thin sheet of tissue which holds the intestine in place).

Blood is classified as a connective tissue. It consists of a *liquid plasma*, the matrix, in which float the *cells* or *corpuscles*. The cells are of two main kinds, red and white. The red cells are far more numerous (five million to every cubic millimetre compared with five thousand per cubic millimetre of white cells) and contain the red chemical haemoglobin, which carries oxygen in the blood from the lungs to the tissues. Many of the white cells are able to engulf and destroy bacteria. Substances produced by the bacteria also kill white cells. These dead cells are familiar as *pus*.

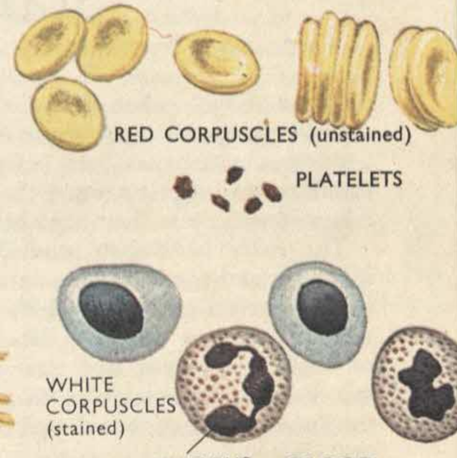
Other small cells in the blood are called *platelets*. These play an important part in the blood-clotting mechanism and they also block any small holes that may occur in the blood vessels. There are about a quarter of a million platelets per cubic millimetre of blood.

All tissues are shown highly magnified and not to scale

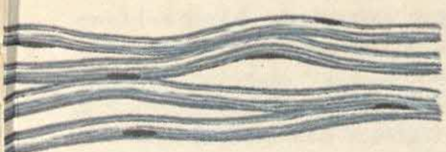
AREOLAR OR LOOSE CONNECTIVE TISSUE



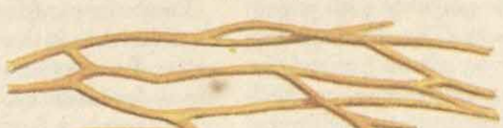
FAT OR ADIPOSE TISSUE



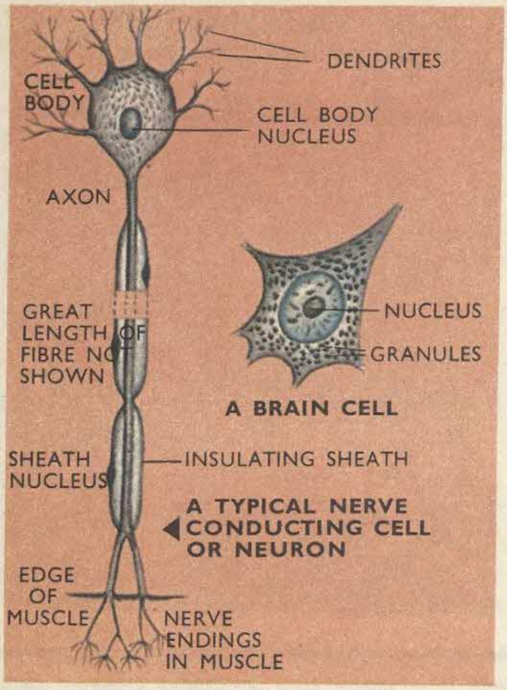
BLOOD



WHITE FIBRES



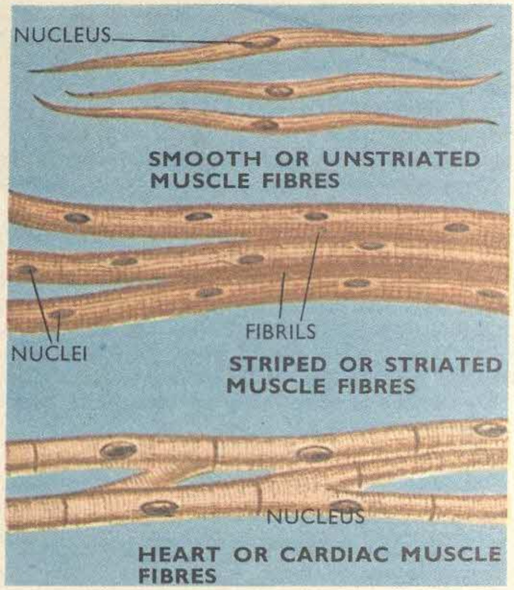
YELLOW ELASTIC FIBRES



The main part of a typical *nerve*-conducting cell is the cell body. This is rounded but from it branch a number of fine branches (dendrites) which receive signals from other nerve cells. A single fine branch, the axon, carries signals away to another nerve cell or to a muscle or gland. Axons passing from the nerve cord to the toes may be three feet long.

Each axon is a long, thin thread of living jelly (protoplasm) surrounded by an insulating layer of fatty materials and protein. Every nerve fibre has a thin membrane round it. A small nerve is a bundle of nerve fibres surrounded by a sheath. Large nerves contain a number of bundles.

Not all nerve-conducting cells have a long axon. Many of the cells in the brain, for example, have one which is about the same length as the dendrites.



Each *unstriped muscle fibre* is about 1/5 millimetre long and 1/150 millimetre wide and has a central nucleus. The fibre tapers to a point at each end. Smooth muscle is capable of slow, sustained contractions such as those that are needed to push the food slowly through the gut.

Each *striped muscle fibre* is about 1/10 millimetre in diameter and may be several centimetres long. Each contains hundreds of nuclei and is made of long, thin strands or fibrils which appear striped with alternate light and dark bands. The width of these bands alters when the muscle contracts.

Cardiac muscle is found only in the wall of the heart. It is composed of fibres which branch and join to form an elaborate network. This arrangement is fitted for the muscle movement needed to enlarge and 'shrink' the bag-shaped heart. The fibres are made up of fibrils and these are striped in a similar way to those of striped muscle. At intervals dark bands or partitions cross the fibres.

Staining tissues and cells

SINCE the 1830's when Theodor Schwann concluded that all living things are made up of cells, each with a nucleus, much has been learnt about cells, their arrangement into tissues and the relationship of their minute structure to their chemistry.

The early histologists studied membranes, tissue scrapings and teased preparations. Their microscopes were imperfect and they had few reagents with which to emphasise any structural details. The development of methods of fixing and staining tissues, especially thin tissue slices obtained with a microtome, enabled the fine structure of the cell and the nucleus itself to be investigated.

Besides making use of various stains to show up cell structure under the ordinary light microscope, new techniques have been evolved whereby unstained structures can be revealed. However, staining is still widely used both in the teaching of medicine and physiology and also in pathology – the routine study of disease.

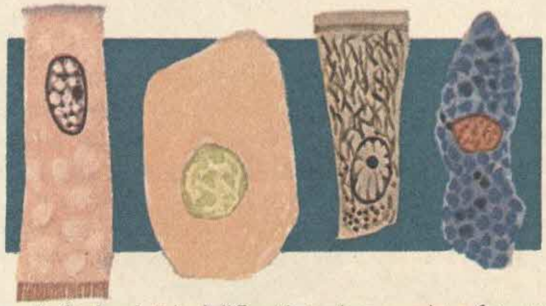
From the practical problem on page 6 you will have discovered that the darker central portion (nucleus) of each cell accepts the methylene blue whilst the surrounding clearer area (cytoplasm) does not. The basic purpose of staining is in fact to highlight details of cell structure, and one way of doing this is to use stains that show up

certain parts and not others. Besides using one stain to do this it is possible (in fact more usual) to use more than one stain. The nucleus is stained one colour and the rest of the cell another colour, or colours. Alternatively, some stains pick out parts of the nucleus and parts of the cytoplasm.

The detailed structure of a tissue can best be seen under the microscope from a thin section. First the tissue must be killed and then it has to be prepared so that thin slices can be obtained readily. The various treatments that it receives are all designed to preserve the cells and their contents so that they suffer as little change as possible. This is extremely important, for the chemical architecture of a living tissue must be destroyed to some extent by any treatment. Only through experience can one distinguish between such 'artefacts' and real structures.

Small blocks of the killed tissue are *fixed* in an appropriate solution (e.g. potassium dichromate). This preserves it in as lifelike a form as possible, allows it to accept stains more readily and also hardens it so that it will withstand cutting much better. After fixing, the tissue is embedded in wax (rigid plant material may be supported with pith or a similar support such as a piece of cabbage stalk) before it is sectioned. This enables it to be cut into very thin slices, $10\mu(1\mu = \frac{1}{10000}$ mm.) or slightly less.

Before staining, the wax is removed from the section with a clearing agent such as xylol. It will then accept stains (wax and water do not mix).



Four cells fixed and stained differently to show a variety of structures.

Practical

A satisfactory introduction to staining techniques is to treat teased muscle tissue from the gastrocnemius muscle of a freshly killed frog in the following way:

1. Place teased-out muscle fibre in hot water – temp. 90° C – for around a minute. (*This fixes the tissue.*)
2. Transfer tissue to a watch glass containing 70% alcohol for 1 minute.
3. Place tissue in a watch glass containing a small quantity of Ehrlich's haematoxylin for at least 2 minutes.
4. Wash thoroughly in tap water.
5. Dry slide (but keep tissue moist) and examine under microscope to see if stain is intense enough. (If not it should be placed in the stain for a further period.)
6. Wash in tap water for a minute or two.
7. Place tissue in 0.5% eosin Y (aqueous) – the counter-stain.
8. Wash in water for about 2 minutes.
9. Dehydrate in alcohol just below 100% strength.
10. Dehydrate in 100% alcohol.
11. Clean by placing in benzene (xylene is an alternative) until tissue transparent.
12. Place tissue on slide.
13. Cover in Euparal (or Canada balsam).
14. Place cover slip over it.

Plant Tissues

Plant tissues

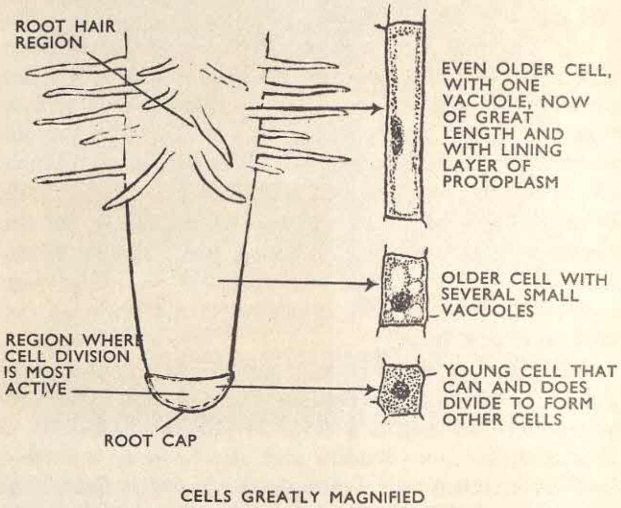
Flowering plants, like animals, are made up of cells. The cells are arranged into tissues, each carrying out a particular task. Thus some are supporting tissues; others transport food from one part of a plant to another; certain tissues in the leaves are the sites of photosynthesis. The cells making up these tissues are of different kinds depending on the function that they have. The supporting cells in the stem, for example, are hollow, box-like structures that are no longer living. They have no protoplasm but merely consist of dead cell walls. These cells also serve to transport water to the leaves. Food-making cells in the leaves, on the other hand, have a lining of protoplasm and they contain numerous biscuit-shaped chloroplasts, the green structures in which starch is manufactured. The cells are filled with cell sap.

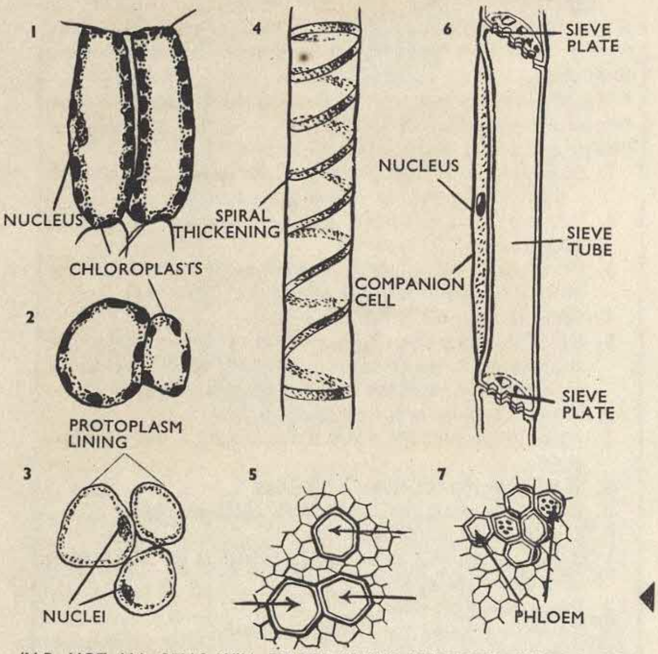
Mature plant cells are very different in appearance in different tissues, but they are all formed from cells in restricted parts of the plant, so-called *meristems* or growing areas. Such cells are located just behind the tip of the root and shoot, for example. Initially a plant increases in bulk by the division of the cells in meristems. At first the cells are rectangular with a central nucleus and full of protoplasm. The cell walls are thin. As they mature many changes in their form take place depending on the tissue that they eventually become. The cells *differentiate*.

The basic changes involve increase in length and the appearance of sap-filled spaces or *vacuoles* within the protoplasm. As the cells get older smaller vacuoles merge until in the typical, mature plant cell there is only one large vacuole almost filling the cell and a thin layer of protoplasm lining the cell wall. In specialised tissues, such as xylem, even more changes occur. The

cell-walls become thickened with lignin – this is often laid down as a spiral thickening – and eventually the cross walls between the cells break down to produce long tubes, ideal for conducting water to the leaves. The living contents of the cell also disappear. In phloem sieve tubes the cross walls do not break down completely but are perforated by many fine holes.

Diagrammatic external view of the end section of a root (below left) with (right) highly magnified views of three cells of different ages. Note that as they age they lengthen and become more vacuolated.





(N.B. NOT ALL CELLS WILL BE SECTIONED THROUGH THEIR NUCLEI)

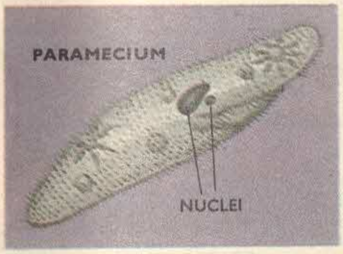
(B) Left. Various cells from flowering plant tissues (not drawn to scale, all highly magnified), 1. Two leaf palisade cells, 2. Two leaf spongy (mesophyll) cells, 3. Parenchyma cells from stem, 4. Three-dimensional view of xylem vessel with spiral thickening, 5. Section across three xylem vessels – arrowed, 6. Cutaway view of a phloem sieve tube showing the sieve plates and the adjacent companion cell, 7. Section across sieve tubes – arrowed.

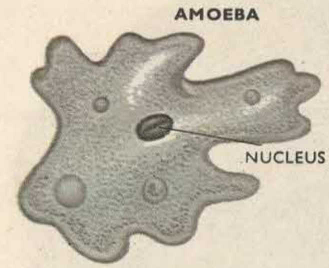
The microscopic structure of cells

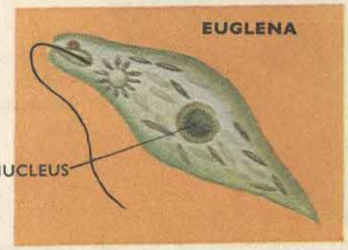
IN 1667 Robert Hooke used a primitive type of microscope to examine some thin pieces of cork. He saw that the cork was made up of tiny units which he called 'cells'. All plant tissues are made up of cells, each having a definite boundary wall of cellulose. Animal tissues lack cellulose walls and the units are less obvious. The term 'cell' is applied to them, however, for it is clear that the contents of each unit are far more important than the boundary. It is within the cell that the vital processes of life are carried out.

The basis of all living cells is protoplasm. It is important to realise that this is not a single substance; it is a very complicated mixture of organic and inorganic substances in which chemical changes are continuously taking place. The chemical composition of protoplasm therefore varies not only between species and between cells performing different functions but also in individual cells at different times. The main component is water in which there are suspended or dissolved numerous *proteins*, *lipids* (fatty substances), *carbohydrates*, and *inorganic salts*. The electron microscope shows that there is an elaborate structure – of fibres and channels – within the protoplasm.

Every cell is bounded by a *cell-membrane*. This is not an external structure but a living part of the cell. The membrane can be seen with the aid of the electron microscope and much other evidence points to its importance. Cells placed in liquid surroundings do not mix with the liquid unless they are pierced with a very fine needle. This suggests some sort of envelope for the protoplasm. Research indicates that the surface layer of the protoplasm consists of a network of protein and lipid (fatty) material which prevents loss of the cell contents and also allows some flexibility. The thickness

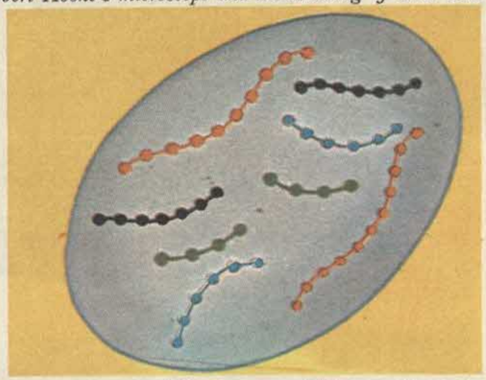






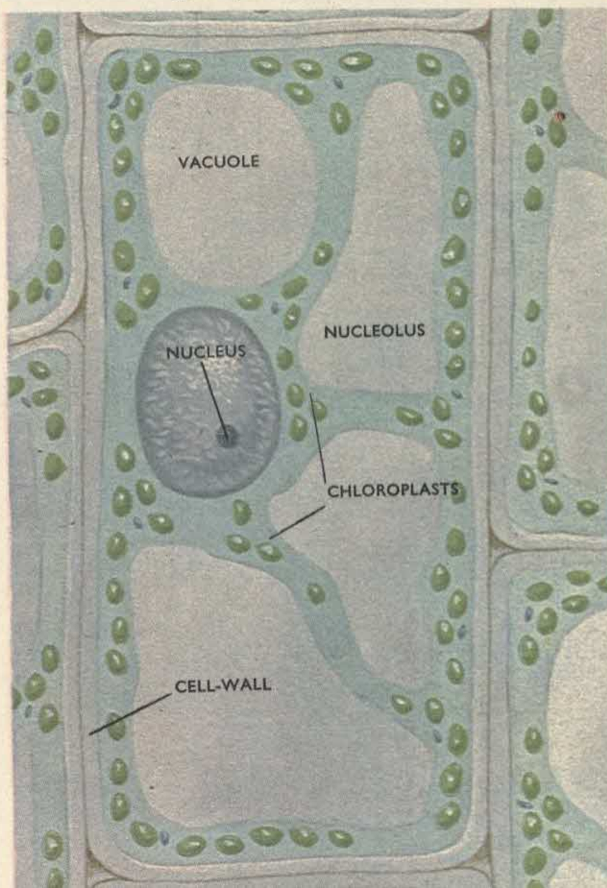
Some protozoans showing typical structures.

Robert Hooke's microscope and his drawing of cork 'cells'.



The diagrammatic structure of chromosomes within a nucleus. Only four pairs are shown. Each bead represents a gene of which there may be thousands on each chromosome. Each chromosome can be paired with another similar one.

A typical plant cell highly magnified.



of this cell membrane layer is less than one thousandth of a millimetre.

The cellulose cell-walls of plants give their cells regular shape. The shape of cells may be controlled by external factors. In animals the shape may be decided by the pressure of the other cells. Many protozoans have shells or other stiff coverings which maintain a fixed shape, while others, such as *Amoeba,* continually change their shape. The protozoans have often been called *unicellular* (i.e. single-celled) animals and compared directly with cells of other animals. However, this is not a fair comparison because in higher animals no cell performs all the functions that a protozoan does. It may be better to call protozoans *acellular* (lacking cells) because their bodies are not divided into cells.

Cell contents

Apart from the protoplasm almost all living cells have other structures in common of which the *nucleus* is best known. This structure controls the whole cell and as a rule there is only one nucleus in each cell. It consists of protoplasm (*nucleoplasm*) which contains certain substances (*nucleoproteins*). These regulate the manufacture of the proteins (see page 36) of the rest of the cell protoplasm (*cytoplasm*). Surrounding the nucleus is a membrane similar to that around the whole cell. There is a darker region within the nucleus called the *nucleolus*.

The chromosomes

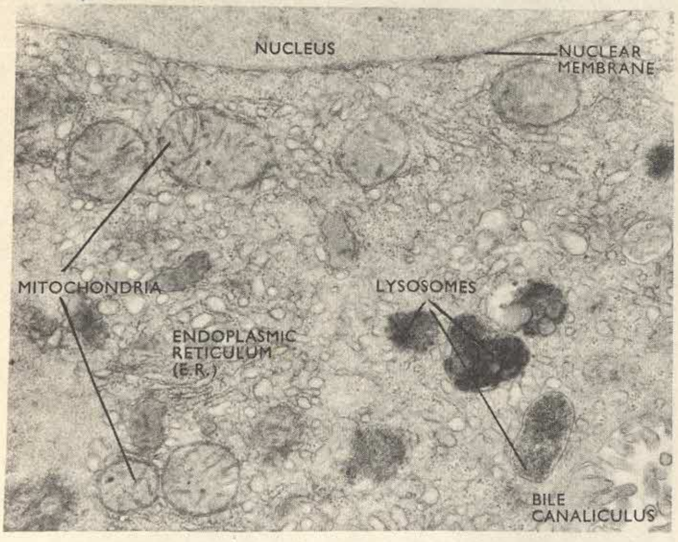
The nucleus has been mentioned as being the controlling body of the cell. It controls not only the working of the cell but also its formation and structure. The nucleoplasm contains a certain amount of denser material which at certain periods (associated with the

A diagram of half a cell showing the nucleus (1) mitochondria (2) Golgi apparatus (3) and endoplasmic reticulum.

reproduction of the cell) becomes clearly visible (under the light microscope) as coiled threads. These are the chromosomes. With certain important exceptions every cell nucleus in the human body has 46 chromosomes. Each one can be matched with one other and there are in fact 23 pairs of chromosomes. In the male there are more correctly 22 pairs and two odd chromosomes. Mouse cells contain 20 pairs while pea-plant cells contain 7 pairs. Morgan and later workers experimenting with the fruit fly *Drosophila* found that it has very large chromosomes in its salivary glands, a factor which helps to make it ideal for heredity experiments.

Lengthwise section through Allium *root tip stained to show the chromosomes. Various stages of cell division can be seen. (Compare with the drawings on page 26.)*

An electronmicrograph of a mouse liver cell showing mitochondria.



Summary

The essential points of the preceding section and their relationship to the genetics section may be summarised as follows:

1. The bodies of animals and plants are composed of cells.
2. Cells, at least at the beginning of their lives, have nuclei and these are embedded in the surrounding cytoplasm.
3. Nuclei contain chromosomes.
4. Cells vary in structure and chemistry according to their position and role in the organism.
5. Organisms differ because they are made up of different arrangements of cells.
6. Yet all the different kinds of cells develop from an egg cell or ovule.

The problem is – *How do the egg cells differ; what decides how they develop?* This is discussed in the genetics section that follows.

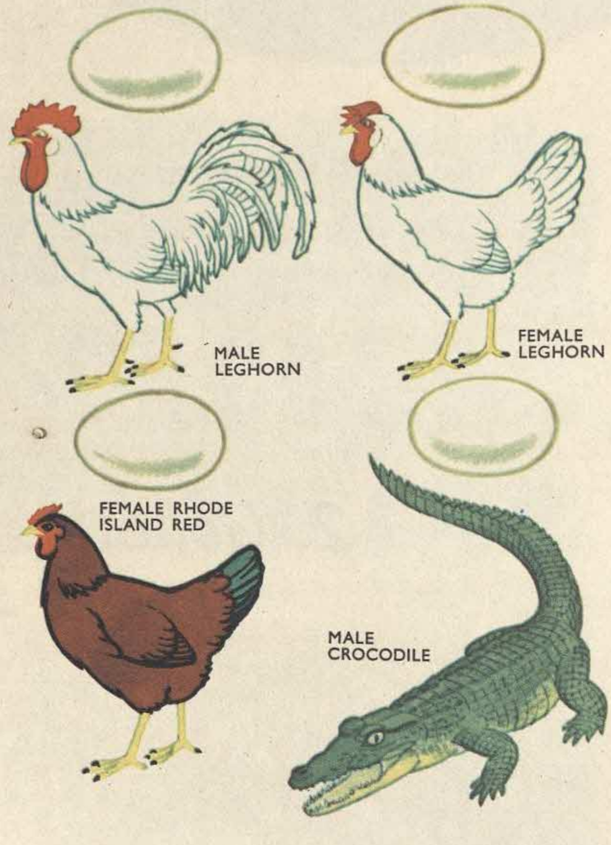
2. Genetics

An introduction to Genetics

IMAGINE four eggs. Each has a shell, a white, a yolk, they are about the same size and weight. When the embryos (that part of the egg which develops) start to grow, they will be, at first, indistinguishable. When the animals are fully developed, however, they are very different.

The science of *genetics* deals with the question 'What decides that each of these eggs will develop into different kinds of animals?'

Broadly speaking, there may be two sets of factors that decide how an egg will develop: external (outside) factors, such as light, temperature, food, and internal factors, which may be thought of as a set of *instructions*.



There are many instances of external factors that affect development – for example, temperature can decide whether a shrimp's eyes will be red or black; temperature governs coat colour in Himalayan rabbits; food value and quantity affect the weight and physical appearance of human beings; a lathe operator's son is less likely to go to university than a doctor's son.

However, it is clear that the outside influences have limits. A crocodile egg placed in a hen-coop still develops into a crocodile; the sex of a bird is not decided by its natural diet.

External factors are often easy to find and measure and we can usually obtain a fairly clear idea of how they operate. Internal factors provide a much more difficult problem. The eggs were almost identical in appearance and even the young embryos are very similar. If there are such things as instructions where are they?

The differences are not apparent to the naked eye. They may be chemical differences or they may be observable with the aid of a microscope. An important clue discovered during this century lies within the nucleus. It can be demonstrated that the nucleus contains threads called *chromosomes* (see page 14). The number of chromosomes in the nucleus of a crocodile's egg differs from that in the nucleus of the fowl's egg. It may be that the chromosomes *are* instructions. One might expect, then, a different number of chromosomes in two kinds of fowl. This is not so, however. Do we reject the idea that chromosomes=instructions for development? Is there any other evidence to support the theory?

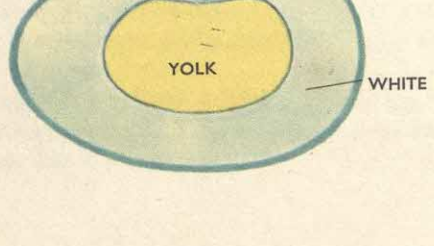
In most animals and plants the number of chromosomes is an even one – man 46, fruit flies 8 – and it is possible to identify pairs of chromosomes of similar length and structure, so that 46=23 pairs, 8=4 pairs. In fact only female humans have 23 pairs, males have 22 pairs plus 2 odd chromosomes, and fruit fly males 3 pairs plus 2 odd chromosomes.

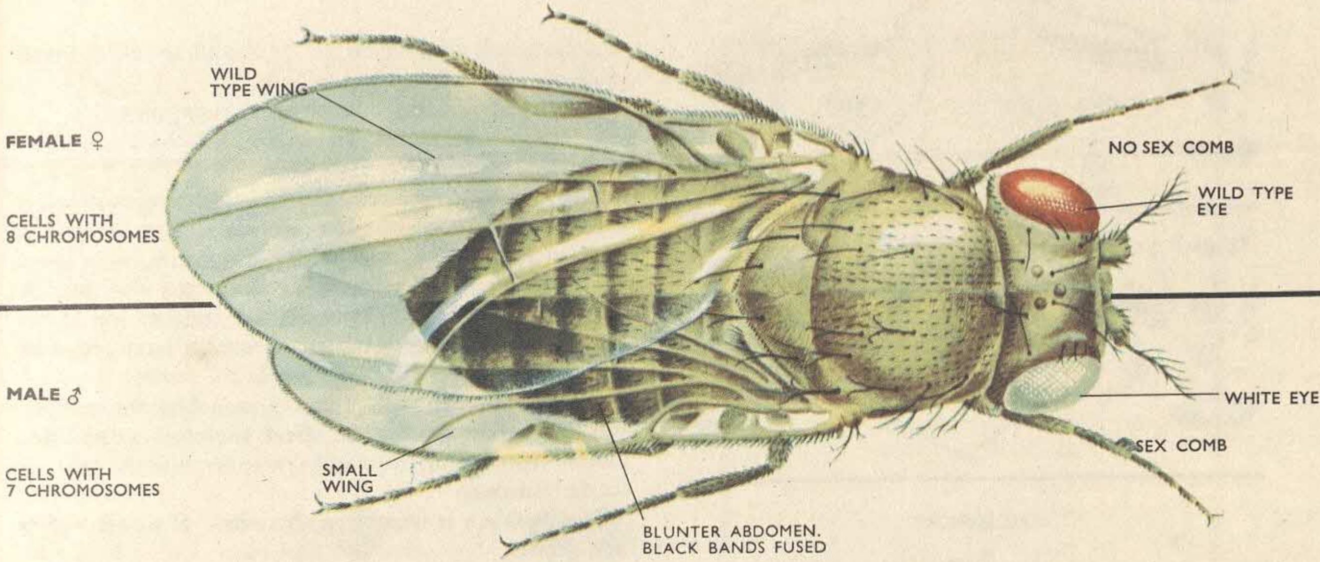
In birds the pattern is reversed, the females have the two odd chromosomes. The interest here is that whether or not a fertilized egg develops into a *male* or a *female* may depend on the chromosome difference. This supports the chromosomes=instructions theory.

Further evidence for this theory is provided by very strange cases of development in fruit flies where one half of the body is female and the other male.

Examination of the nuclei in the cells of such insects

A simplified diagram of a section through a hen's egg.





A gynandromorph (half male, half female) of the fruit fly, *Drosophila melanogaster.*

reveals that nuclei in the female half have 8 chromosomes, and those in the male half have 7 chromosomes.

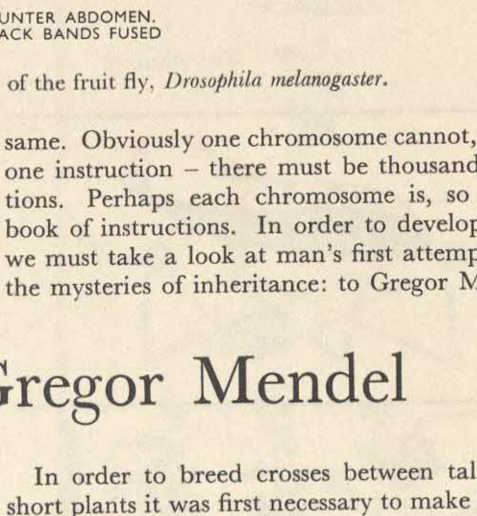
The theory although well supported by evidence is still not complete, however. The two hens illustrated at the beginning of the section have exactly the same number of chromosomes and yet they are not the same. Obviously one chromosome cannot, simply, give one instruction – there must be thousands of instructions. Perhaps each chromosome is, so to speak, a book of instructions. In order to develop these ideas we must take a look at man's first attempt to unravel the mysteries of inheritance: to Gregor Mendel.

The work of Gregor Mendel

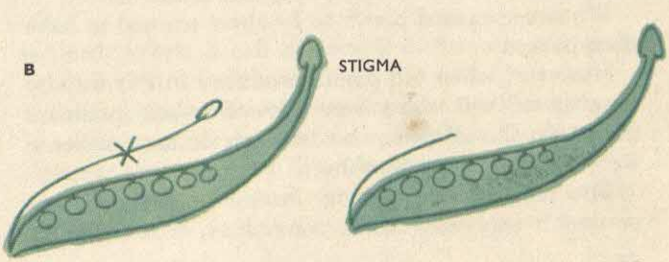
THE ways in which characteristics are passed on from one generation to the next have intrigued biologists for a very long time. Gregor Mendel was the first person to establish some sort of system in this field. He was a monk and taught science at a school in Brunn – now part of Czechoslovakia – in the middle part of the nineteenth century. The principles that Mendel discovered hold good today and form the basis of the science of genetics which has practical value in plant and animal breeding.

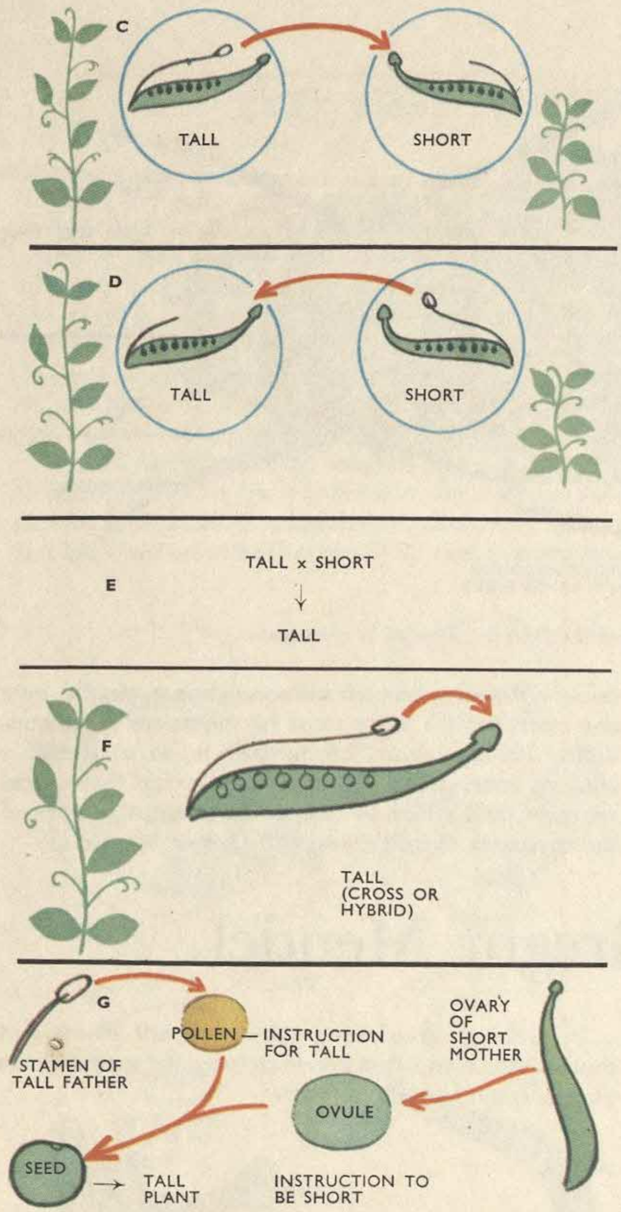
Mendel experimented with garden peas which he grew in the garden of his monastery. He noticed that not all the plants were alike: some were tall, others short; some seeds were round while others were wrinkled. These characters were clear-cut and obvious and Mendel decided to study them individually. The fact that the flowers are usually self-pollinated was a great help to Mendel, for his flowers were not contaminated by unknown pollen. Mendel selected plants with opposed characters (e.g. tall and short) and bred them individually until he was satisfied that he had true-breeding lines, i.e. the tall plants produced only more tall ones.

In order to breed crosses between tall plants and short plants it was first necessary to make sure that the flowers could not self pollinate:



In order to prevent this the stamens had to be removed before they were ripe – i.e. while the flower was still in bud.





Mendel's experiments – see text for explanation.

The pollen from the stamens of a tall plant had to be transferred to the stigma of a short plant the stamens of which had been removed (Illus: C).

The same cross was made the other way round (Illus: D).

The seeds when ripe were collected and planted. All the plants which developed were tall (Illus: E).

Whatever caused plants to be short seemed to have disappeared.

However, when tall plants produced in this way by crossing tall with short were allowed to self pollinate (Illus: F), the offspring showed both characters. Some were tall and some were short.

The ratio of tall to short in one of Mendel's experiments was 6020 tall to 2001 short, that is almost exactly 3 tall to 1 short or 75% tall to 25% short.

There were two problems here,

(1) Whatever caused shortness has reappeared

(2) This 3:1 ratio was given in all such crosses *providing enough plants were used.*

Now, the 'instructions' as to how a seed must develop must be contained either in the ovule or in the pollen grain or in both. A plant with a tall father but a short mother must have received its instructions to be tall (so to speak) from the pollen grain contributed by its father. A plant with a tall mother must have received its instructions from its mother via the ovule.

So, it looks as though (Illus: G) somehow the instruction to be short has had no effect, therefore we call this factor' (instruction, if you like) *recessive*, and the tallness factor' *dominant*.

The problem is what happens now. If we have two such plants,

Tt × Tt

what instructions do they hand on in their pollen and ovules?

If they handed on both sets of instructions the next generation of peas would carry not two but *FOUR* sets of instructions

Tt Tt

TTtt

and would presumably be all tall.

There are two difficulties to this theory, (a) the plants of this generation were not all tall, but 3 tall to 1 short, (b) it is difficult to see how the sets of instructions could keep on increasing in this way.

It is easy to produce a theory which explains the result.

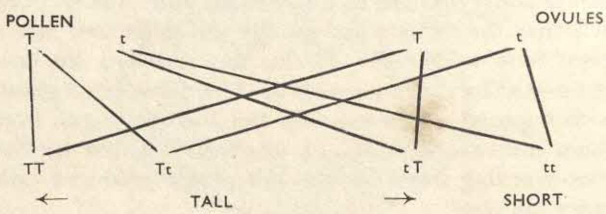
Consider the hybrid parents with their *two* lots of information.

Tt and Tt

If only one set of information got into the sex cells, pollen or ovules, then we would have

(T)– or (t)–carrying pollen and
(T)– or (t)–carrying ovules

and *if* equal numbers of T and t pollen grains were produced it would be equally likely that T type pollen could combine with T or t type ovules. The complete pattern would be

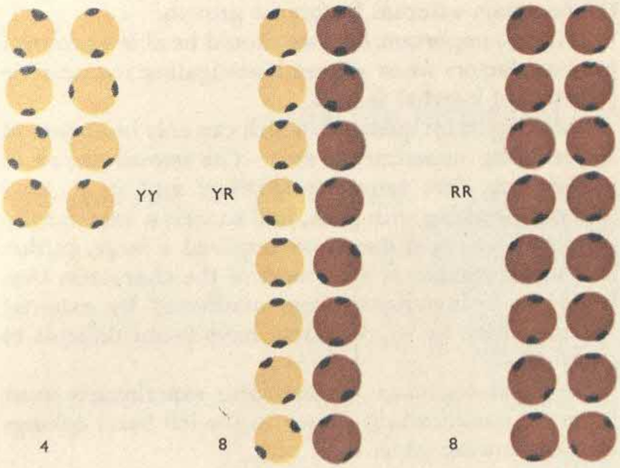


Of these seeds $\frac{3}{4}$ would become tall plants (*remember tall instruction is dominant, short recessive*) and $\frac{1}{4}$ short plants.

This theory can be illustrated by an experiment. Given a jam jar full of beads $\frac{1}{2}$ yellow, $\frac{1}{2}$ red and a Kilner jar full of beads $\frac{1}{2}$ yellow, $\frac{1}{2}$ red. Let jam jar represent stamens, kilner jar represent ovaries. Shake both well. Pick out 1 bead from the jam jar equivalent to the pollen grain and 1 bead from the Kilner jar equivalent to the ovule, and record the colours.

Some possible results:

	Yellow Yellow	Yellow Red	Red Red
Score			
20 pairs of beads	4	8	8



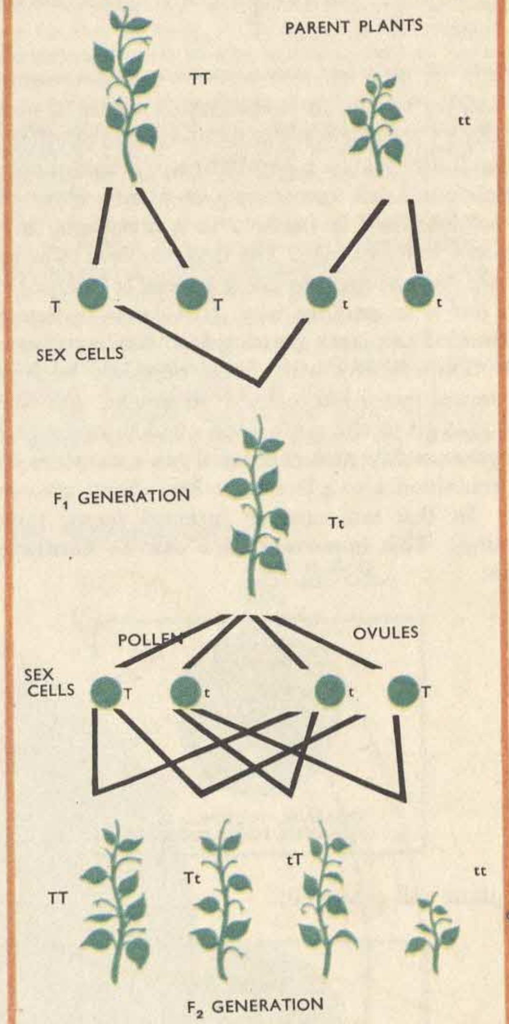
40 pairs	12	20	8
80 pairs	18	39	23
etc.			

Fairy-tale to fact

The above explanation is a guess (hypothesis if you like) and no more, unless we can support it with evidence.

Think for a moment about the demands of the theory. A plant receives two bits of information affecting the same thing – the way in which it grows – and hands on *one* bit of information to each of its offspring, moreover it hands on one bit of information to half its offspring the other bit of information to the other half. For over 60 years this *theory* remained no more than a guess until a very exciting discovery was made.

The sex cells, like all cells, have nuclei. These nuclei contain stainable threads, the *chromosomes*. In any species of animal or plant the number of chromosomes



When tall and short plants are crossed the F_1 generation are all tall. Two types of gamete are produced and these give plants in the ratio 3:1, tall: short.

is fixed. When a cell divides, the chromosomes must make duplicates of themselves.

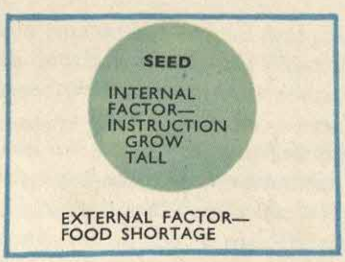
Read the accounts of what happens to chromosomes in *ordinary cell division* and in *cell division leading to the formation of sex cells*, see if (with a bit of help from your teacher) you can find the evidence which almost clinches the above theory.

Experiments with *Drosophila*

THE way in which an investigation starts in genetics is usually by the discovery and description of differences between individuals in a population of plants or animals. Mendel found tall and short pea plants; short plants may be described as being 2 to 4 feet high, and tall plants as 6 to 8 feet high. The first problem to be solved is – *Is the shortness character due to external or internal factors?* or, to put it in another way, *Is it due to environment or inheritance?* Pea plants growing in infertile soil exposed to low temperatures will almost certainly be stunted. An external factor has 'caused' shortness. But Mendel found that given the same good conditions for growth, when presumably each plant will grow as tall as it can, some remained 2 to 4 feet tall when others grew much taller. In this last case an internal factor must be operating. This important idea can be illustrated as follows:

This plant will grow tall.

This plant will grow short.



This plant will grow short.

Now suppose that we have 3 seeds and what we wish to find out is – *Do they contain different internal instructions to grow tall or short?*

It is obviously important that they are grown in the same conditions which as far as we know contain all the necessary external factors for growth.

It is also important that we should be able to control external factors when we are investigating the possible presence of internal factors.

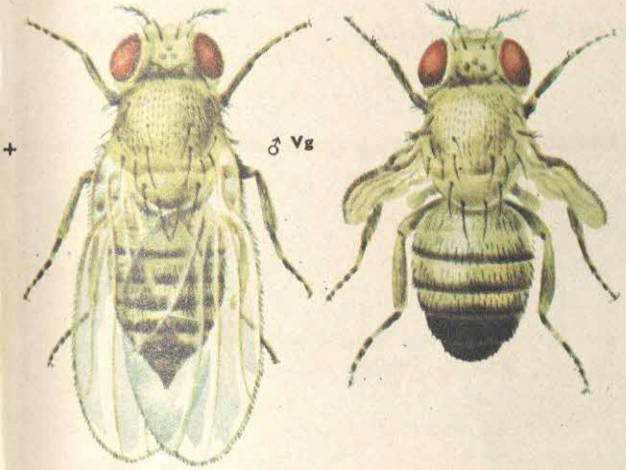
Two important questions which can only be answered by breeding experiments are – *Can internal factors be handed down from parents to offspring?* and *if so, how?* Mendel, working with peas, had to wait a year for the results of an experiment, he required a large garden and was fortunate in that most of the characters that he chose to investigate were unaffected by external factors, which he would surely have found difficult to control.

An ideal organism for breeding experiments must have the qualifications shown in the left hand column of the following table.

Ideal characteristics for breeding experiments	*Drosophila melanogaster*
1. short life history – breeding several times a year.	1. egg to mature adult 10 days at 25°C.
2. easily visible distinct differences between one character and its alternative.	2. eye colour – body colour – normal and vestigial (stunted) wings easily visible, all occur as characters.
3. easy to tell males from females.	3. banding on abdomen differs in males and females, can be seen with 3-inch lens if not unaided eye.
4. small, easy to control environment.	4. adults about 2 mm long. 50 to 100 can live in a 1″ by 3″ glass tube.
5. produce a lot of young at each mating.	5. each female lays fifty – hundred eggs.

As an introduction to *Drosophila*, consider the problem following.

These flies (shown right) have either *normal* wings or *vestigial* (stunted) wings. (These are not the only possible wing shapes.)

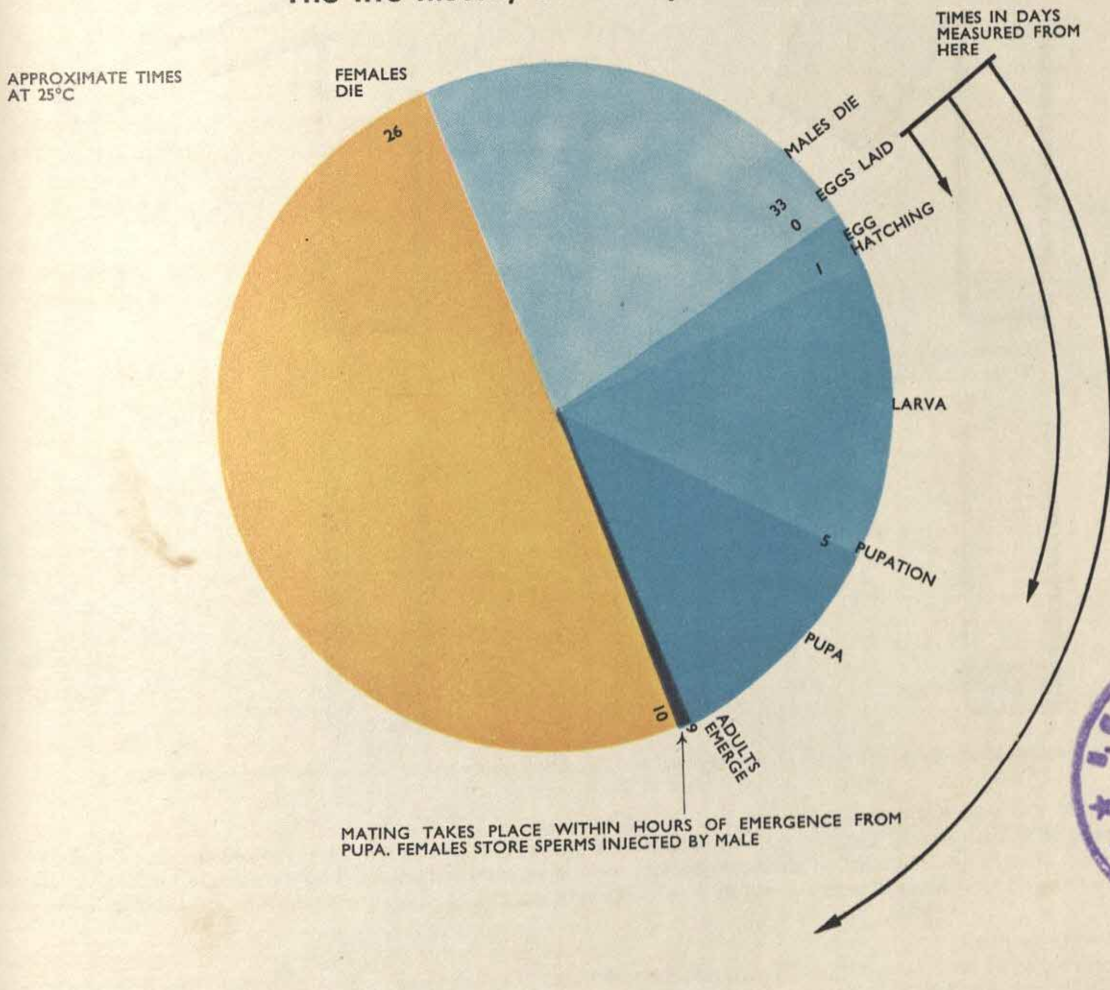


If we wish to find out if this condition is passed on from parents to offspring we will have to mate flies of one type with flies of the other type. We will have to provide the right conditions for flies to mate, to lay eggs, for the maggots to grow, to pupate and finally emerge as adults. It will be necessary to distinguish male from female flies. We must be able to put flies to sleep (to anaesthetise them) so that they may be transferred from one tube to another and sexed and counted when necessary; and of course they must be anaesthetised to the right level so that they wake up at the required moment. Matings must also be arranged between males of one sort and females of another sort ensuring that the females have not previously mated. This sounds very complicated but the techniques involved are straightforward and easy to learn. The account of the techniques given is designed to help you to tackle the breeding of fruit flies with confidence.

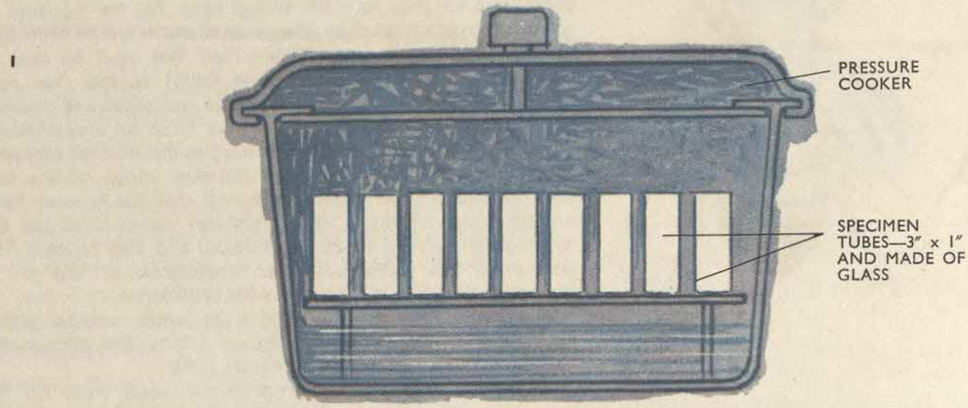
Apart from the initial collection of virgin females, which your teacher will do making use of a binocular microscope, you can perform all the experimental work.

Firstly try the vestigial wing-normal wing cross for the first (F_1) generation and then the second (F_2) generation, comparing your results with those of Mendel in his experiments with peas.

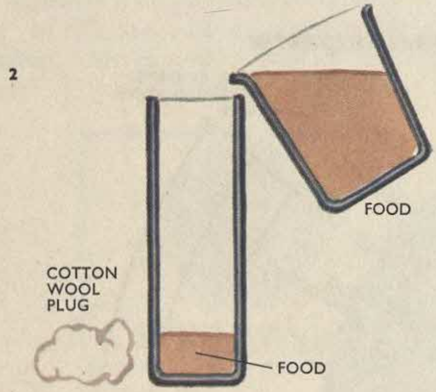
The life history of *Drosophila melanogaster*



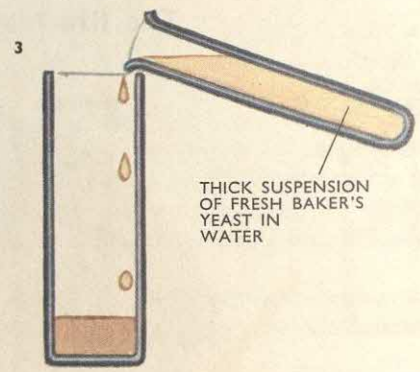
How to maintain stocks of *Drosophila*



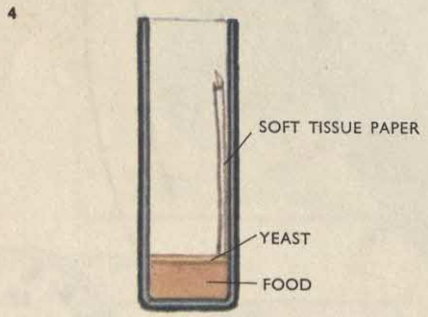
1. Sterilize 3″ 1″ glass tubes. 15 mins @ 15 lbs./sq. in.



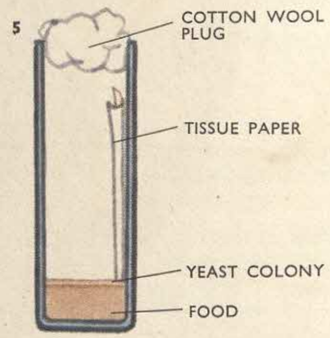
2. Pour food (see below for preparation) into sterile tubes to ½ inch depth. Plug with cotton wool. Cool to set.



3. Add a small quantity of a thick suspension of baker's yeast.



4. Push a strip of folded tissue paper into food near side of tube.



5. The culture bottle is now ready to receive flies.

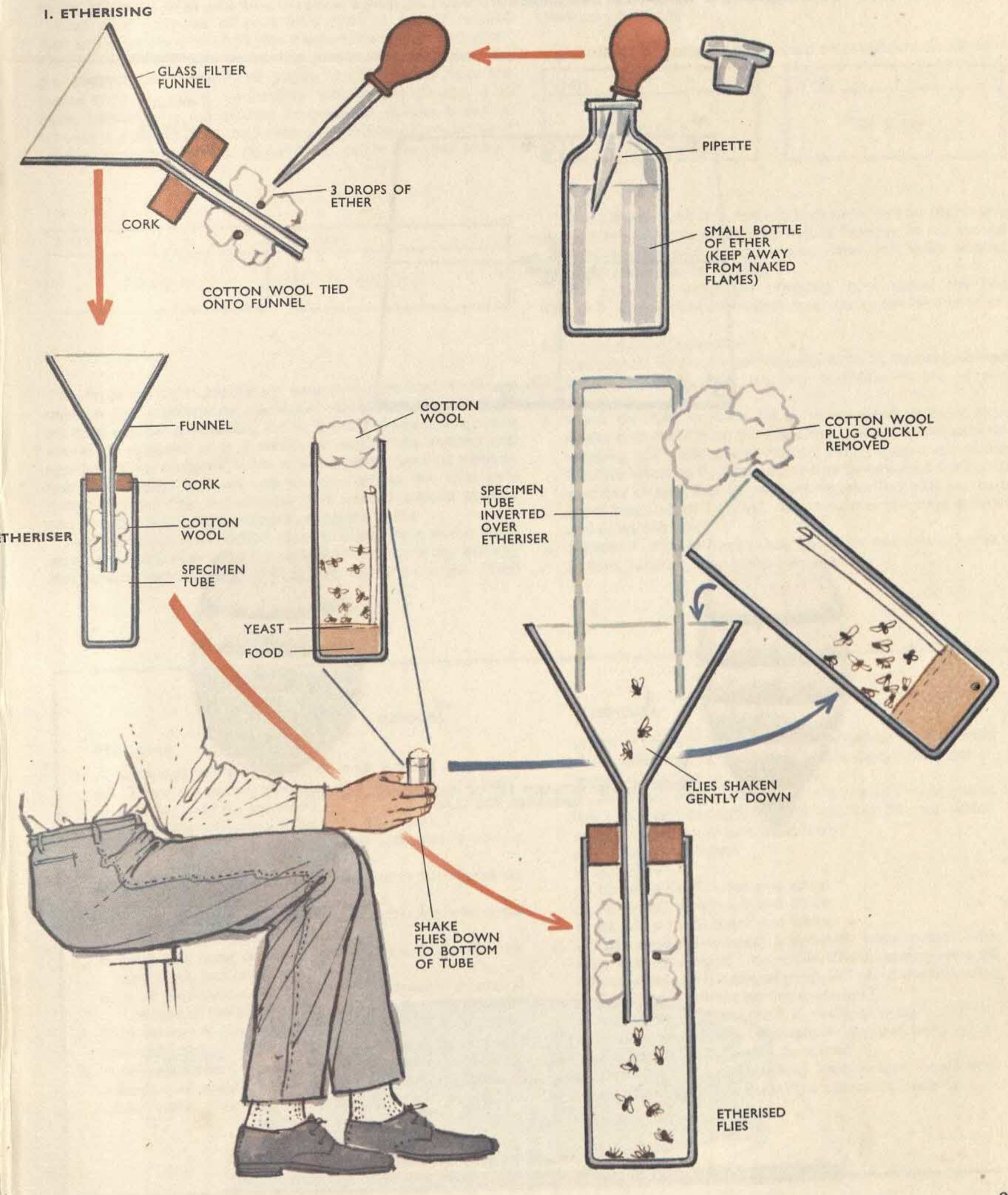
Making up food and use of fungicide

a. soak 72 gms. of oatmeal in 120 c.c. of water. b. dissolve 35 gms of black treacle in 40 c.c. of water. c. *BOIL* 6 gms. of agar in 400 c.c. of water. *ADD* a pinch of moldex or nipagin and the oatmeal and treacle. Boil the mixture for 20 mins. stirring from time to time. Add a little water until the mixture stirs fairly easily, but don't add too much; the food must set firm when cold.

Important points to note

1. Keep cultures between 20°C. and 25°C. 2. Avoid sudden changes in temperature. 3. A laboratory bench cupboard with a 25–watt bulb makes a useful incubator.

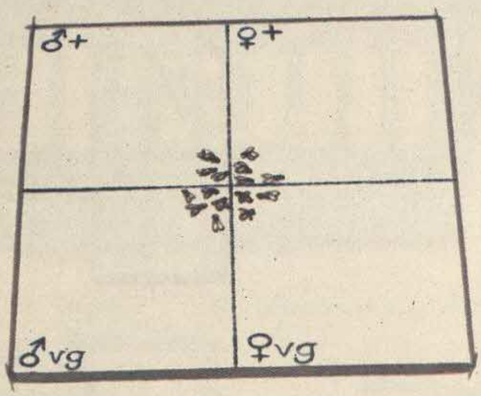
How to handle *Drosophila*



Sexing and Scoring

If male and female, normal and vestigial-winged flies were present in the culture, mark a white tile with Biro thus:

+ = NORMAL
Vg = VESTIGIAL WING
♂ = MALE
♀ = FEMALE



♀ ABDOMEN

♂ ABDOMEN

(BOTH AS SEEN WITHOUT AID OF MICROSCOPE—THOUGH ENLARGED FOR CLARITY)

EMERGENCY ETHERISER

Setting up a cross

In order to cross normal- and vestigial-winged flies proceed in the following way.

First of all cultures of pure wild type or normal-winged flies and of vestigial-winged flies are purchased from a supplier. Usually when the flies arrive the parent flies are dead and the offspring are maggots or pupae. As flies hatch from the pupae they are sexed, and males and females (6 and 3 of each respectively) are placed in prepared culture tubes to provide a stock of pure-bred flies of each type. Each bottle is labelled according to the flies it contains, in this case either:

A

DATE
♀Vg × ♂Vg

DATE
♀Vg × ♂+

In order to make absolutely sure that pure-bred lines are used in the experiments the initial sample may be used to produce another generation. If this is decided upon, the adults would be removed after a week, by which time mating and egg-laying has occurred. After a further week the next generation will emerge and we can check them to see that only normal-winged flies are coming from normal-winged parents and vestigial forms from vestigial-winged parents.

As soon as you are satisfied, clear all adults from all the tubes on a certain day (day 1) at 9 am. At 5 pm the same day sex any flies which have emerged from pupae during the night. Place the females, which will be virgin unmated flies, into a separate tube. Repeat at 9 am and 5 pm the next day until you have sufficient virgin females of both stocks. You are now ready to make up your cross.

B

DATE
♀Vg × ♂+

DATE
♀+ × ♂Vg

Place 6 males with 3 females in each case. Set up two tubes, in one place vestigial males with normal females, in the second vestigial females with normal males. After one week remove the parents and get rid of them.

After a further week the offspring, now called the first filial, or F_1, generation, start hatching and they can be examined.

The second filial generation

If we wish to find out what happens if the F_1 flies are allowed to mate with each other we may continue in one of two ways.

a. Leave the flies to mate for a further week (this is three weeks after making up the first cross – or one week after the hatching of F_1 flies). Now remove the F_1 flies. It is possible that late hatching F_1 flies may have to be removed during the next day or two, but do not remove any flies after ten days (from hatching of F_1 flies). After a further ten days etherise and score the flies.
b. Transfer F_1 flies to fresh tubes. Leave for one week. Remove F_1 flies. Score F_2 flies when they hatch.

Problems

1. A black and white rat is mated with a black and white rat. There are seven offspring of which five are black and white, and two are white.
   Which of the following statements are correct?
   a. the female must previously have been mated with a white male.
   b. the female must be carrying the factor for whiteness but not the male.
   c. the male must be carrying the factor for whiteness but not the female.
   d. both rats must be carrying the factor for whiteness and black and white.
   e. it is impossible to distinguish between a and d because of the small number of rats.
2. If in several matings of these rats 36 had been black and white and 14 white, which statements would be true?
3. A white rat from a white/white cross was mated with a black and white rat from a black and white/black and white cross. The offspring were all black and white.
   Which of the following describes the genetic constitution of the offspring? a. dominant, b. heterozygous, c. monohybrid, d. haploid, e. recessive.
4. If black and white rats from the cross (3) were mated five times and produced litters totalling 50 rats, which of the following ratios is most likely?
   a. 50 black and white
   b. 50 white
   c. 10 white to 40 black and white
   d. 36 white to 14 black and white
   e. 24 white to 26 black and white.
5. Female vestigial-winged *Drosophila* were mated with male normal-winged *Drosophila*. The offspring were 90 normal wing to 10 vestigial wing. Which of the following conclusions is correct on this evidence?
   a. normal wing is dominant to vestigial wing.
   b. normal wing is not dominant to vestigial wing.
   c. the normal flies are not pure bred.
   d. some of the vestigial-wing females had mated with vestigial-wing flies before the cross was made up.

The Reproduction of the Cell

The plant or animal body is made up of millions of cells, each finely constructed for a particular purpose. One may well ask what controls the structure of the cell; what ensures that each muscle fibre or plant cell is just like its neighbour and different from cells of another tissue.

We know that each cell in the body contains in its nucleus a fixed number of chromosomes. When cells divide the number of chromosomes remains constant. This arrangement exists in almost all living cells and is called *mitosis* (my-toe-sis).

For ease of description the process is divided into a number of stages although of course it is really continuous. A very generalized account is given in picture and caption form below.

When the cell is not in the process of dividing, the chromosomes in its nucleus are not clearly visible under the ordinary light microscope. The length of time required for mitosis varies from species to species but an average of six to twenty-four hours is a reasonable figure.

Reduction of the chromosome number

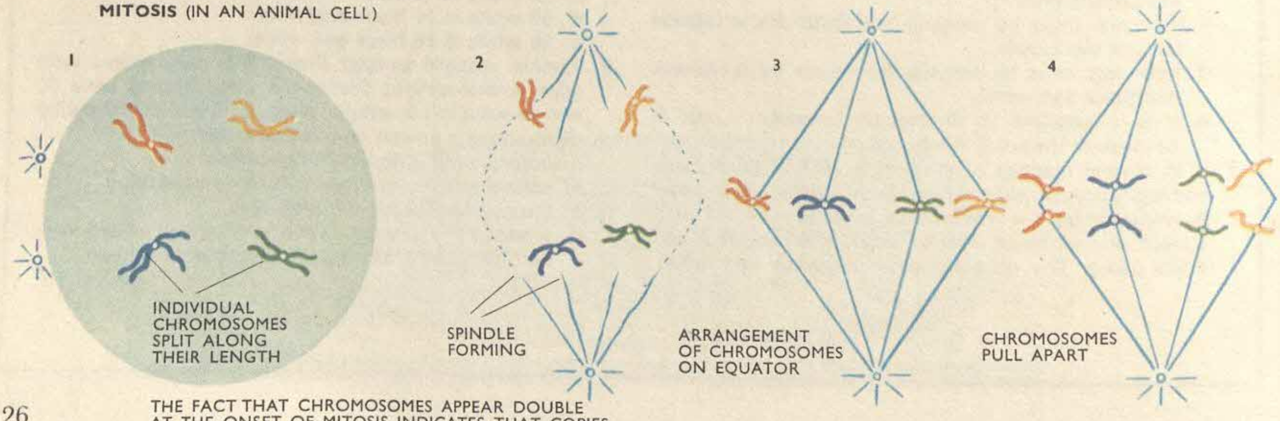
The reproductive process in most plants and animals involves the joining of nuclei from the two parents. If each parent nucleus had a pair of each type of chromosome, the offspring's nuclei would have two pairs and so on. This state of affairs would soon become impossible and there is a special arrangement in almost all organisms whereby the chromosome number is halved at some stage of the reproductive process. This process is called *meiosis* (my-oh-sis). The normal body cells contain two of each type of chromosome – the *diploid* condition. The sex-cells are formed from these by meiotic division and each then contains one set of chromosomes (the *haploid* condition). Like mitosis, meiosis can be divided into several stages (see illustrations and captions).

If we return to Mendel's tall and short peas cross experiment we can start to understand one of the most remarkable and exciting connections in the whole of biology. You will recall that hybrid plants from the cross were tall and that these tall plants when self-pollinated gave *both* tall and short plants in the ratio of 3 to 1. To explain this result we invented a theory which used the idea that although a plant may contain instructions for tall and short, the pollen grains or ovules would contain one instruction only, either tall or short.

During meiosis a cell containing say 12 chromosomes produces sex cells which contain 6 (if you like, 2n and n respectively chromosomes). Of the 6 pairs (12 individual chromosomes) only one member of each pair (6 individual chromosomes) gets into the sex-cell (*continued on p. 28*).

Mitosis

The division of a cell and its nucleus is called *mitosis*. The chromosomes, which cannot be seen with an ordinary light microscope when the cell is not dividing, appear as double threads (1) soon after mitosis starts. The diagrams below show what happens to four chromosomes, one red, one blue, one green and another orange, during mitosis. As mitosis proceeds they become arranged (2) on a network of strands – called the spindle – eventually lying around the equator of the spindle (3). The two threads of which each chromosome is made then pull apart (4) towards the opposite poles of the spindle so that four lie at one pole and four at the other (5). A membrane then forms around each set of four chromosomes and the cell becomes



THE FACT THAT CHROMOSOMES APPEAR DOUBLE AT THE ONSET OF MITOSIS INDICATES THAT COPIES MUST HAVE BEEN MADE DURING THE SO-CALLED 'RESTING PHASE' BETWEEN DIVISIONS

Meiosis

During the formation of sex cells the number of chromosomes is halved, so that each sex cell has half the number of chromosomes possessed by each of the body cells. When male and female sex cells join during fertilization, therefore, the full number of chromosomes is made up again. The process by which the chromosome number is halved is called *meiosis.*

During the early stages of mitosis (see below left) the chromosomes appear as double threads. This is not so in meiosis. The chromosomes are single threads (illustration A; in these pictures the fate of four chromosomes is followed). They then come together in pairs (B) forming two pairs, the chromosomes of each pair lying closely together. Each chromosome then divides into two by splitting along its length (C). The pairs of double chromosomes become arranged on the equator of the spindle which has by this time formed. The split chromosomes then pull apart from each other but they remain attached at one or more points (D). The pairs of chromosomes then become arranged on a spindle much as in mitosis (stage 3), and the individual chromosomes move to the poles, each chromosome of each of the two pairs pulling away from each other. The net result is two daughter cells (F) each containing two split chromosomes – half the number (four) in the original cell. For this reason meiosis is often referred to as a reduction division. The number of chromosomes is reduced to half. Following the reduction part of meiosis is a second division (similar to mitosis) in which each of the daughter cells divides into two, forming a total of four sex cells or gametes, each containing two chromosomes.

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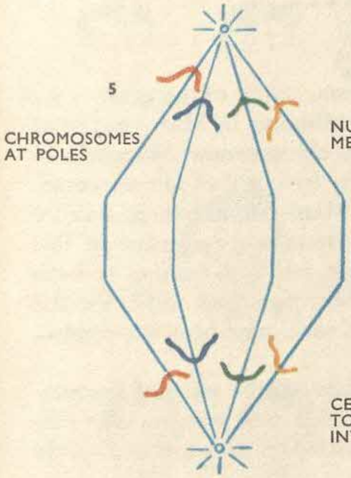
thinner (constricts) between each set (6). Eventually the constriction passes right across the cell and a new cell wall is formed resulting in the formation of two daughter cells each with four chromosomes in its nucleus (compare photograph, page 14).

5



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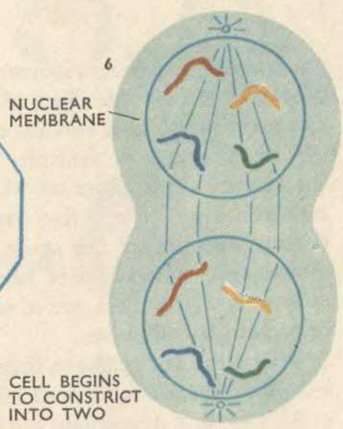
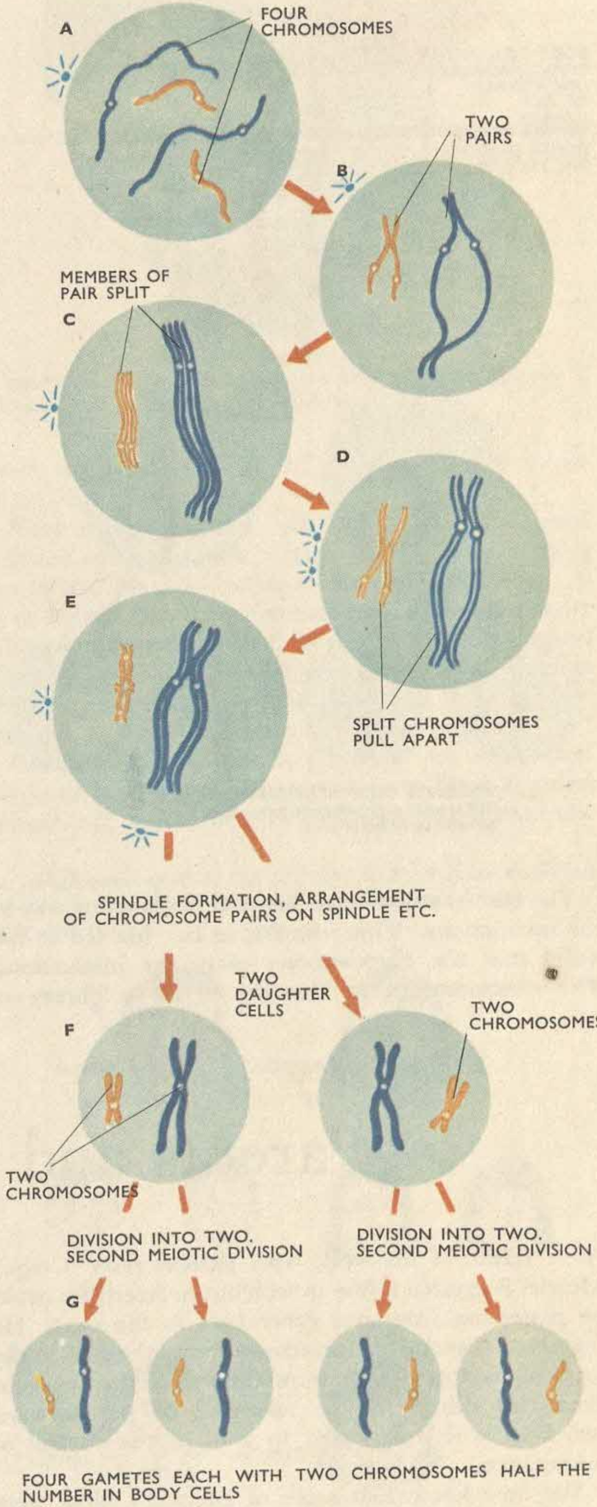
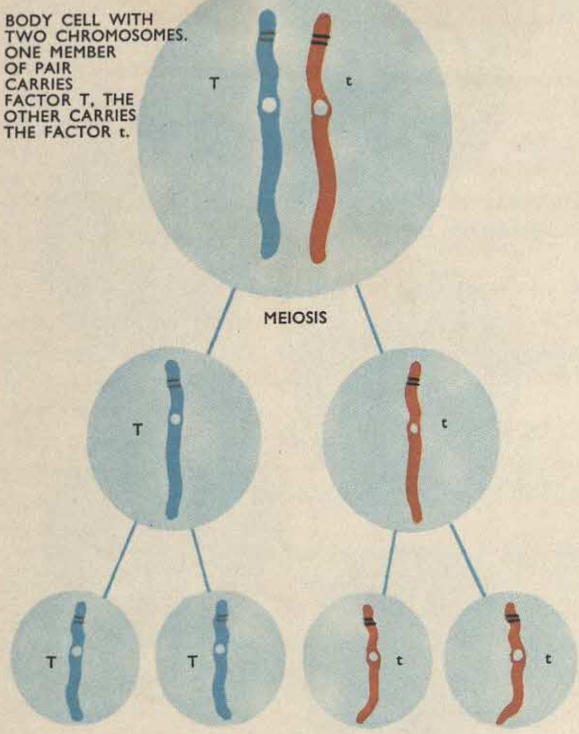


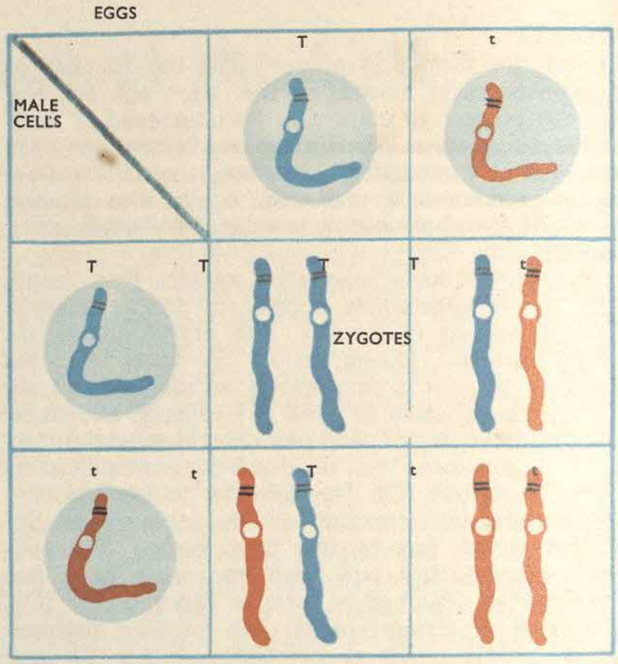
MEIOSIS





SEX CELLS EACH WITH ONE CHROMOSOME. Half the sex cells will carry factor T, and half will carry factor t.

The chromosomes have behaved in the same way as the instructions. This remarkable fact has led to the belief that the chromosomes carry the instructions. The chromosomes are thought to be a 'library of



instructions', which are followed as the organism develops.

To picture how this mechanism might work study the diagram on the left in which two chromosomes only, i.e. two of a similar pair, are considered.

A hybrid plant would produce both male and female sex-cells of the above types. If two such plants cross or if such a plant self-pollinates, the behaviour of the chromosomes may be illustrated thus, as above.

Parents and their offspring

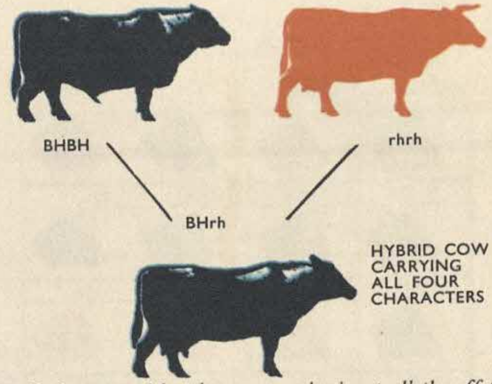
As A result of his work with garden peas, Gregor Mendel suggested a way in which characteristics could be passed on from one generation to the next. He suggested that the characteristics were inherited in the form of 'factors' which were carried in the sex-cells. From his discoveries he was able to put forward two laws which appeared to explain the control of inheritance.

We now know that some of Mendel's ideas were correct and we can explain them. What he called 'factors' are now called *genes*. They can be regarded as 'chemical messengers' which pass information from parents to offspring. The genes occur on thread-like structures – the chromosomes. Each of the genes – for example, those controlling albinism in Man – occur at a certain point on a certain chromosome. The cells of the body normally contain two *sets* of chromosomes (or twenty-three pairs in Man) so that there will be two genes governing the presence or absence of this defect. If both are the same, i.e. both normal or both albino, the individual is *homozygous*, or pure, for the character. If there is one of each gene he is *heterozygous*, or hybrid for albinism.

When the sex-cells are formed, the pairs of chromosomes separate and one of each pair goes to each sex-cell. This is in agreement with Mendel's first law – only

Mendel's Laws

In his first law – *the law of segregation* – he stated that: only one of *a pair of opposed factors* (e.g. tall or short growth factors) *can be carried in a single sex-cell.* The second law – *the law of independent assortment* – stated that: *each one of a pair of factors may combine with any one of another pair.* In other words, to use Mendel's own examples, round peas can be green or yellow and so can wrinkled peas. Also the ratios given could only be the result of a random combination of freely assorted factors.



Because black coat and hornlessness are dominant all the offspring of this match will be black and have no horns.

one of a pair of genes can be in a single sex-cell. Each one of a pair of chromosomes can go into a sex-cell with any one of another pair.

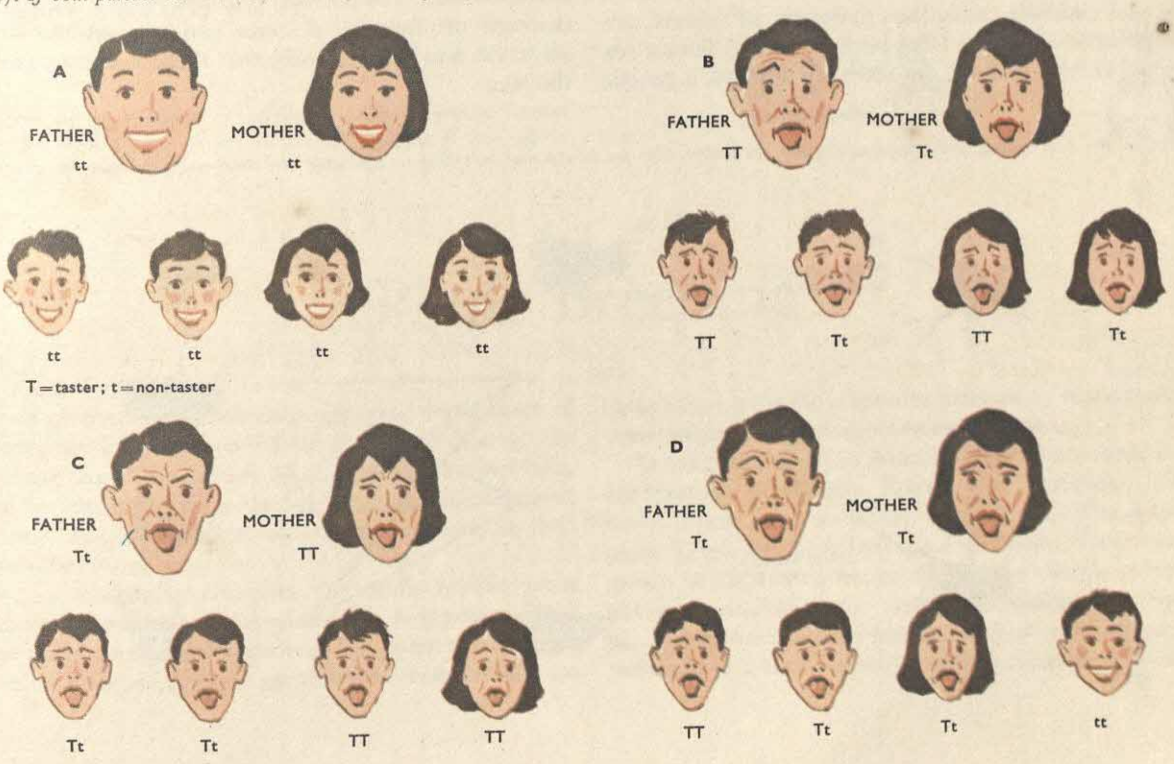
Mendel's laws can be used to predict the characteristics of offspring of given parents, provided that the characteristics are due to the action of a gene or genes. It is important to distinguish between *genetic effects* and *environmental effects* caused by differences in diet, upbringing, etc.

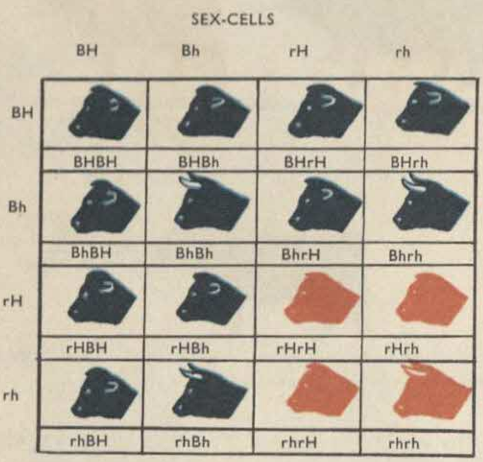
Most human traits, such as hair colour, are produced by the action of several genes. However, it has been discovered that the ability to taste a chemical, phenylthiocarbamate, is inherited as a simple Mendelian dominant, just like round seed shape in peas. The ability to taste P.T.C. is incidental to our ordinary sense of taste and it cannot be acquired through training. Either you can taste it or you can't! The way in which the ability to taste P.T.C. is inherited is shown in the illustrations.

Black coat dominates red coat in cattle. A cross between red and black animals will produce nothing but hybrid black offspring in the first generation. If these hybrid black ones are crossed, about a quarter of the next generation will be red, half will be hybrid black and a quarter will be pure black. The 3:1 ratio of black to red is called the *monohybrid* ratio because only one pair of characteristics is being studied.

Hornlessness in cattle is dominant to the horned condition and a cross between a pure black hornless animal (e.g. an Aberdeen Angus) and a red, horned one

The ability to taste phenylthiocarbamate is dominant to the inability to taste phenylthiocarbamate so that (A) when both father and mother are non-tasters (tt) all the children are non-tasters (tt). If one parent is TT and the other Tt (B and C) then all the children will be tasters (TT or Tt). If both parents are Tt (D) however, then they may have a non-tasting child (tt).





When two hybrid black hornless cattle are crossed, four types of offspring will result. Wherever B occurs the animal will be black. Where H occurs there will be no horns.

will result in hybrid black, hornless first generation offspring. Because any one of a pair of characteristics can combine with any one of another pair, the second generation will show four types in the proportion, black hornless 9: black horned 3: red hornless 3: red horned 1. This ratio is called the *dihybrid ratio*. When three, four or even more characters are considered a fixed proportion is still obtained.

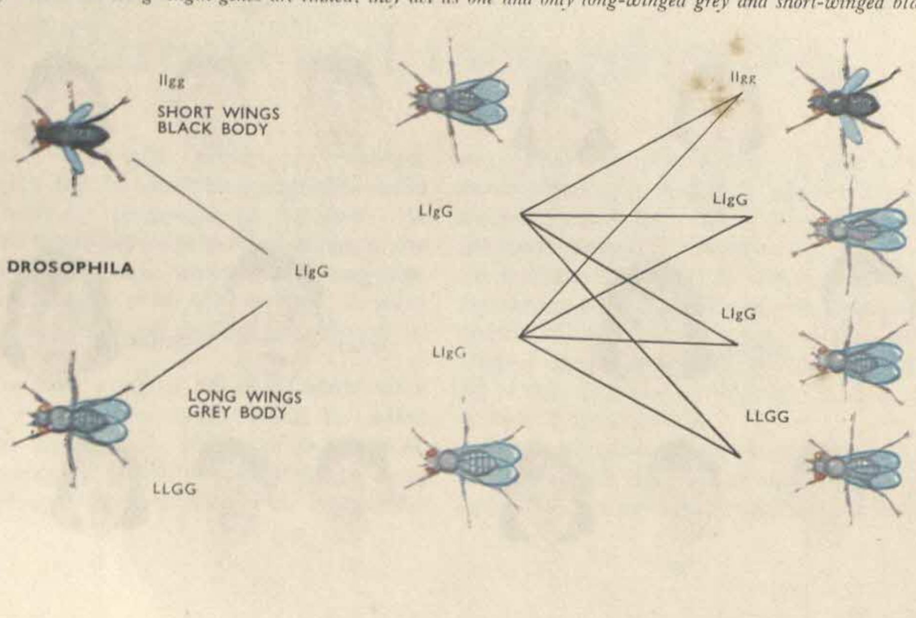
Male or female?

Many animals and the majority of plants are *hermaphrodite* – i.e. they have both male and female sex organs. In those where the sexes are separate a genetic mechanism normally decides whether an individual may be male or female. Although it is usually stated that Man has 23 pairs of chromosomes, there are, in the male, only 22 *pairs*, plus two odd ones called the *sex-chromosomes* or the *X* and *Y chromosomes*. The female has two *X* chromosomes, making 23 true pairs. When the sex-cells are formed the pairs separate so that each female cell (egg) has an *X* chromosome. Half the male cells will contain a *Y* chromosome and the other half an *X*. If a male cell containing an *X* chromosome fuses with an egg-cell a female will develop, whereas a male cell containing *Y* will produce a male embryo. Because the *X* and *Y* are present in equal numbers boys and girls will be produced in nearly equal numbers too. The female is not the *XX* sex in all animals. In birds the hen is *XY* while the male is *XX*.

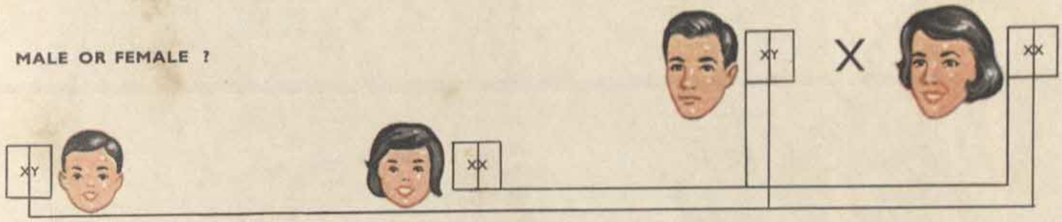
Sex-linked genes

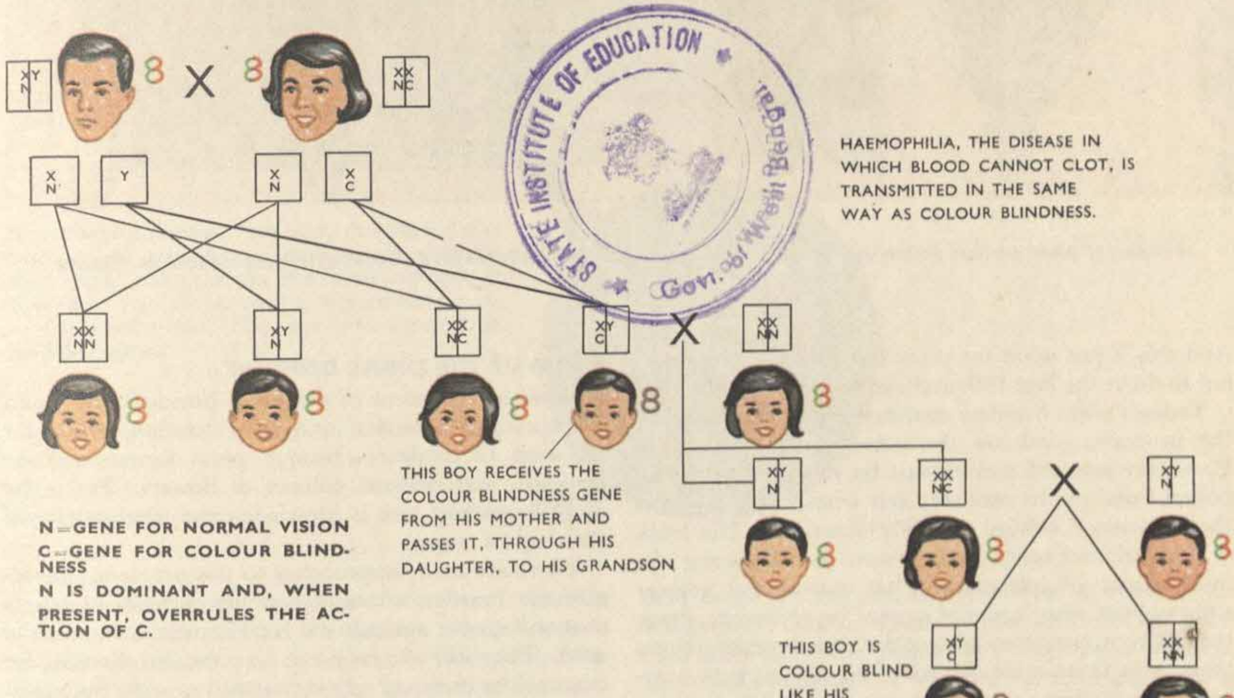
The *Y* chromosome in Man rarely carries genes which are not concerned with sex, but the *X* chromosome, which is larger, does carry some other genes. The characteristics that these produce are said to be *sex-linked*. Red/green colour-blindness, in which the sufferer cannot distinguish between red and green, is an example. The gene is recessive to that for normal vision so that, except in the very rare cases in which two colour-blindness genes occur together, women do not suffer from this defect. They do, however, act as carriers and may pass the gene to their offspring. If a male receives this recessive gene he will be colour-blind because there is no normal vision gene on the *Y* chromosome. The colour-blindness is thus transmitted through the female. A man cannot pass the defect on to his son because only the *Y* chromosome goes to the son.

Because the body colour and wing-length genes are linked, they act as one and only long-winged grey and short-winged black flies appear.



MALE OR FEMALE ?





Red/green colour blindness is sex-linked. Affected persons cannot distinguish red and green so that the two-colour figure '8' will appear to them as one colour only.

Plant Breeding

MAN had been unconsciously applying some laws of inheritance long before Mendel's time. Using the principle that 'like breeds like' he had, for instance, bred his domestic animals for the qualities he most desired. Similarly with agricultural plants he has exerted his influence.

By automatically choosing the seeds of the most productive and successful plants he has perpetuated favourable qualities. Hundreds of years of artificial selection have altered our agricultural crops to such an extent that today it is usually difficult to trace them to their original wild ancestors.

As long ago as 1719 Man attempted to control the fertilization of plants. Pollen was artificially transferred from one carnation to another. The field of plant breeding had become extended. Here was a means of improving crops other than merely selecting the most suitable seeds. Artificial crossing of strains of plants (or *hybridization*) meant that different characters possessed by closely related varieties could be combined.

Varieties of wheat produced by artificial mutation. Both natural and artificially produced varieties of a plant are used for breeding.

And this is just what the plant breeders were attempting to do in the late 18th and early 19th centuries.

Today's plant breeders continue this work. Basically the processes used are the same as 200 years ago. Plants are selected and crossed by simply transferring pollen from one to another. But what has changed is the knowledge behind the hybridizations. The work of Mendel and other investigators, in explaining the mechanisms of inheritance, has introduced greater surety about what can and cannot be achieved. From the different varieties of a plant the breeder selects those with favourable qualities. He attempts to combine together the genes which are responsible for these qualities into one plant – usually with a fair degree of certainty.

Mutations

New variations are constantly occurring in plants. They are caused by *mutations* – small changes affecting the chromosomes. If the mutation is disadvantageous, the plant, in competition with other plants, will probably not survive to reproduce.

In different surroundings the successful mutations will also be different and so a number of varieties of one type of plant may come into existence. It is from these varieties that different favourable qualities can be selected.

Today plant breeders also are able to stimulate mutations in plants. Using radioactivity or applying certain chemical compounds, offspring from parent plants can be made to display a variety of different characters. Most will be unfavourable but there is just the possibility that one will be valuable.

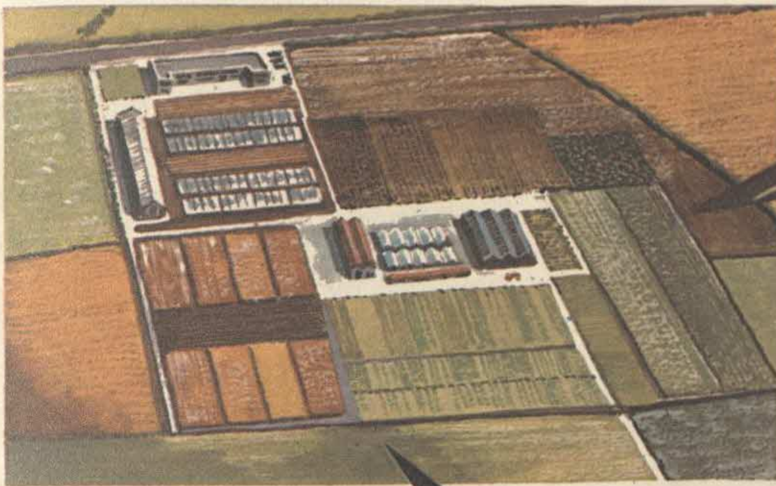
Aims of the plant breeder

What are the aims of the plant breeder? He could of course, by selection and hybridization, breed for all sorts of qualities – bizarre petal formations, for instance, and unusual colours of flowers. But a far more important task is improving the productivity of the world's crops.

There are many approaches to this problem. Basically the breeder wants to provide varieties of plants that will ensure agricultural land is most economically used. The yield of a crop can be increased directly, for example by breeding wheat that will provide the maximum weight of grain per ear. But also important are such factors as resistance to disease and pests, hardiness, drought resistance, length of ripening time and, in the case of cereal crops, the quality and strength of the straw.

It is no good having a variety of wheat that will produce large quantities of grain only in ideal conditions. Strong susceptibility to disease or pests could make the crop valueless; similarly, weak stalks would mean that the wheat is flattened by the first strong wind or torrent of rain. The breeder must compromise. Taking into account the climatic factors of a region, the soil and the diseases and pests, he must provide a crop which will produce well under the natural hazards likely to occur. He must manipulate the favourable genes of different varieties until he produces a plant with all the right characters.

Sometimes the necessary qualities are not noticeable in the outside appearance of the plant. An instance is the malting ability of barley, which depends



Plant Breeding Institute, Cambridge, from the air. Extensive ground is needed for testing newly developed plants. Right: plants protected from chance pollination by 'Cellophane' bags. Below: seeds of different varieties are sown in parallel rows. Their rate of development can easily be compared.

upon the biochemical activities of the plant. Whether a potato will be suitable for making potato crisps is another character not predictable from mere inspection. The breeder here has to analyse the composition of the plants and tries to establish just what chemicals are responsible for the properties he needs to perpetuate.

One other factor the breeder must allow for is the different farming methods that come into use. For instance, modern methods of combine-harvesting operate best with cereals having relatively short stalks. The plant breeder has to see that, amongst other properties, his variety possesses the necessary genes for correct length of stalk.

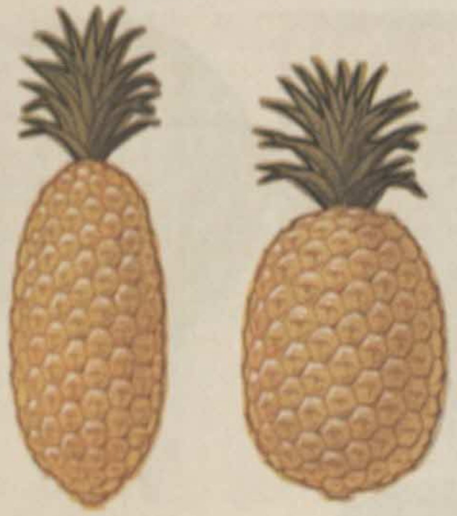
Operations in plant breeding

Long years of work face the plant breeder. The development of a new variety of plant takes at the minimum 10 years and usually a lot longer. For this reason the problems undertaken must be important ones. The solutions must offer prospects of real advancement in crop growing.

When presented with a problem the plant breeder first ensures that breeding is the correct answer – that poor crops are not just the reflections of mineral deficiencies in the soil. Then he must look into the genetical make-up of the plants with which he is working. The desired characters, whether for increased size or disease resistance, must not only be controlled by genes but they must be characters that are identifiable and measurable so that progress in the breeding experiments can be assessed.

Increasing the productivity of a plant by giving it some additional desirable character means that a closely related plant must be found that already possesses the desirable character. The genes responsible for controlling this character must then be incorporated into the first variety. At the same time any undesirable characters likely to reduce the productivity must be excluded.

The actual crossing or hybridization of the plants is a simple task and requires only a pair of forceps and a brush for transferring the pollen. But some plants, most cereals for example, are naturally self-fertilizing – that is, pollen produced by one individual fertilizes the ovules of the same flower. To prevent this from happening, the pollen-producing anthers can be removed at an early stage of their development.



The external appearance and quality of plants is controlled by genes (factors) present in the chromosomes of the reproductive cells.

Disease resistance

The most prominent diseases attacking crops vary in different parts of a country, and plant breeders bear these regional problems in mind. Within a region, however, variation in weather from year to year will determine just what type of disease may prosper. Accurate weather forecasting on such a scale is not possible at present. If it is difficult to breed plants with high resistance to all likely diseases in an area, there is a possible alternative. Seed can be mixed; varieties of a plant can be sown together differing in their resistances to the different diseases. Whatever disease attacks, only a part of the crop will be susceptible and as the susceptible plants are likely to be surrounded by resistant plants a large-scale outbreak is prevented.

Another problem is that the organisms responsible for disease (the pathogens) can change – a crop previously showing strong resistance may be susceptible to the new form. Plant breeders cannot predict these changes. They can only keep a constant watch for the appearance of a new form and attempt to counter the threat before large-scale damage is caused.

Both in self-pollinating and cross-pollinating plants there is always the chance that flowers will be fertilized by stray pollen blown about in the air. So Cellophane bags are tied firmly over the flowers.

The seeds produced from artificial pollination are planted and the offspring examined. Many of the offspring will be no good at all. But just one or two might possess something approaching the correct combinations of genes, and these are kept for further breeding.

Plant breeding establishments need a large acreage of ground for testing the plants they have bred. The plants are sown and their appearance and growth compared with those of their parents and those of other varieties. The different varieties are planted so that as far as possible the composition of the soil is the same for all of them. Changes in the properties of the plants then reflect different genetic constitutions and not different conditions of growth. The breeding establishments are also equipped with greenhouses, freezing apparatus and controlled growth rooms so that plants can be tested under all sorts of conditions.

Theories about the way in which Chromosomes work

A difference of one chromosome makes all the difference between maleness and femaleness in beetles. In mammals, the absence of one piece of a chromosome has the same effect as the absence of a complete chromosome in beetles. Each species of animal and plant has its characteristic number and pattern of chromosomes. This is just some of the evidence that supports the idea that chromosomes 'decide' that one fertilized egg will develop into one kind of organism, another fertilized egg into another. It is reasonable to think of chromosomes as *instructions* which the developing plant or animal follows. But there are difficult problems in understanding how these instructions work.

Some pine trees have 24 chromosomes in each nucleus, so do the cells of some salamanders. It would be reasonable to guess that the chromosomes of pine trees must be of a very different chemical make-up from those of salamanders.

Chemists have successfully investigated the chemical nature of chromosomes having first separated them from cells. It seems that no matter which organism, plant or animal is used as the source of chromosomes, the chemical nature of the chromosomes is very similar. Now how can 24 chromosomes which are chemically very similar cause one egg to become a pine tree and another to become a salamander?

Further information supplied by chemical analysis was that chromosomes contained chemically-linked sugar molecules, phosphate groups and almost always four other substances (which will be referred to by their initial letters, A, T, G, and C) – linked to form a long chain molecule.

The sugar and phosphate content of the chromosomes from different organisms is the same weight for weight.

The main differences found between chromosome analyses were in the amounts of A, T, G, and C. This is not a very promising start in a search for an explanation of the difference between all the different species of living organisms.

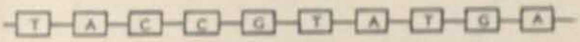
An important additional bit of information supplied by the analysts was that the amount of substances A and T were always the same, the amounts of substances C and G were the same but the amounts of A+T and C+G varied from one species to another. It was already known that, because of their properties A and T would go together easily, so would G and C, but combinations A–G; A–C; T–G; T–C were much less likely to occur. This information, scant though it is, was the foundation on which important theories were laid.

The information was first used to solve a simple problem – simple that is compared to how chromosomes work – how do chromosomes reproduce themselves?

Chromosome replication

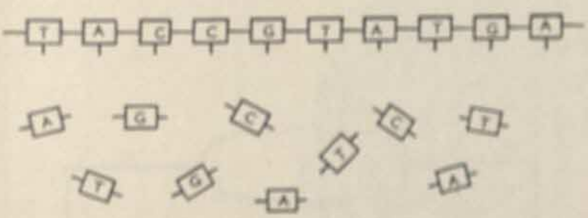
As a result of cell division each new cell contains a complete set of chromosomes. Chromosomes must be able to make copies of themselves. This remarkable property is at the very root of life. The molecules usually studied by chemists may combine to form crystals or to form chains, but the idea of a molecule being able to take from its surroundings units from which it duplicates itself is very remarkable indeed. How might this be done?

From the information provided by the chemists we can invent a theory. Let □ = a sugar and phosphate molecule. Then a long chain 'chromosome molecule' would look like this:

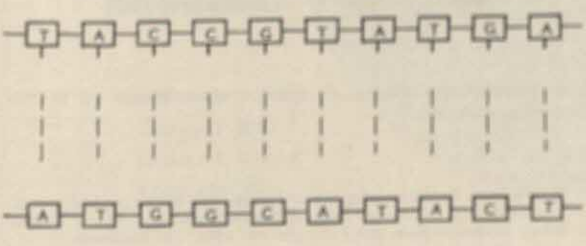


The sugar and phosphate molecules are seen joined to form a chain. Side branches on the chain hold the four substances A, T, G, C, onto the chain. To fit the evidence the chain has been given 2 C and 2 G molecules, and 3 T and 3 A molecules so that the number of C's equals the number of G's, and the number of A's equals the number of T's, but the total number of C+G and the total number of A+T are not equal.

Now imagine such a chain lying in a 'soup' containing free T, C, A, G, and -□- units. Such a situation might be found in the nucleus of a cell.



We know that T combines readily with A, and C with G, so we can imagine a second chain being formed thus:



If these chains were to separate, the process would be repeated. The chain is able to reproduce itself so long as it is provided with 'food', that is to say a supply of A, T, C, and G molecules plus energy required for linking processes.

From X-ray diffraction pictures which can be obtained when X-rays are passed through a powder of 'chromosome molecules', chemists can build up a model of the molecule. This evidence suggests that the DOUBLE chain formed as described in this account is the normal state and that only when mitosis occurs do the halves separate and behave in the way described. How does this affect our original idea of the structure of a single 'chromosome molecule'? Do the proportions of T:A and C:G units in a *single* chain have to be as shown in diagram 1? Note that we can now alter our model to fit this new fact – a good example of scientific detection.

Instructions for development

The only way in which 'chromosome molecules' could possibly carry information which might cause one egg to become a human being and another a dog, is in the form of a CODE. It is useful to think about codes before we go on. Consider the Morse code, used in telegraphy, made up of two units, a dash and a dot. By arranging up to four dots and/or dashes in sequence, it is possible to transmit the complete works of Shakespeare, and any other message, in English for that matter, e.g.

A = . —   S = . . .   E = .   C = — . — .

and

. — . . . . = A S E

. . . . — = S E A

and so on.

If the Morse code is modified a little, we can begin to see a parallel between coded messages and 'chromosome molecules'. We could devise a code in which there were two types of dot, a blue dot . and a red dot . , and two types of dash, a blue dash — and a red dash —.

To complete the analogy, let red — = substance A, and blue — = substance T, let red . = substance C and blue . = substance G, in the 'chromosome molecule'.

The differences between species

While we normally recognise differences between species or varieties of plants and animals, by their structure, such as number of legs, or shape of leaves, there are other differences we could use by which we can separate groups, or even individuals. We could use chemical means, for example, petal colours in flowers, or blood groups in mammals and birds. It is even possible to distinguish by chemical analysis between sea urchin eggs of different species which are otherwise indistinguishable at early stages of their development.

That part of the weight of living things which is not water or skeletal material is mainly protein. Each species has its own particular proteins, many proteins may be similar but a few are unique to a species. We could, if we knew enough about the chemistry of protoplasm, describe and classify species by the proteins they contain. Indeed, work in this field has thrown up some very interesting evidence of value in the study of evolution. For instance, there is strong chemical evidence for presuming that the gorilla and the chimpanzee are more closely related to man than they are to the orang-utan and the gibbon. Similarly whales are more closely related to the even-toed ungulates than they are to any other mammals.

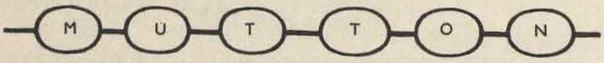
Now it may be that a species develops in a particular way, characteristic for that species, because it produces proteins characteristic of that species. But how is it decided which kind of proteins will be made by the egg protoplasm?

Proteins vary from soluble powders, such as casein, to tough fibres such as keratin. All proteins can be digested, down to amino acids, and appear to be made up of chains, each link of which is an amino acid.

Proteins differ because the types of amino acids they contain are different, and because they contain different proportions of the same amino acids, or because they contain the acids joined in a different sequence.

The way in which cells grow depends on the way the protoplasm grows, which depends on the proteins which are formed, which depends on the way the amino acids are strung together. Imagine a protein from a cow (very much simplified)

consisting of three amino acids, B, E, and F, one of which is represented twice in the protein molecule. A protein from a sheep might be:



The proteins differ because the amino acids they contain are different.

The problem is, what decided that in the developing cow's egg the amino acids B - E - E - F were pieced together in this particular order to form a chain but not other amino acids which must have been available (after all, both animals eat grass)?

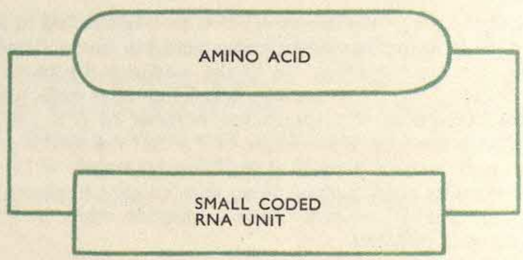
Up to now we have thought that the chromosomes in, say, a cow's egg decided that the egg would become a cow. Is there any connection between the chromosomes and the manufacture of protein? If we knew where the proteins were made in cells a useful start would be made on this problem. This has been investigated by mincing liver cells and centrifuging (spinning) the mince to separate the nuclei from the rest (the cytoplasm) and 'feeding' the separate fractions with radioactive amino acids. Any proteins are then recovered, and if the proteins are radioactive we can say that the radioactive amino acids have been joined up to form the radioactive proteins.

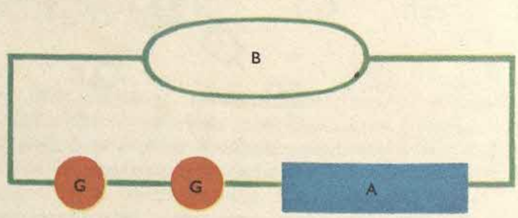
The results of this investigation showed that the nucleus does not make protein, but the cytoplasm does. We can only conclude that there does not appear to be a *direct* connection between protein manufacture and 'chromosome molecules'. Fortunately, the story does not end here. The nucleus contains what we called 'chromosome molecules', made up of chains of sugar, phosphate, and A, T, C, and G. Now cells also contain a similar substance called RNA which also contains sugar and phosphate units and three of the four substances A, T, C, G.* Of the total amount of this substance present in the cell usually 9/10 occurs in the cytoplasm, 1/10 in the nucleus.

There is evidence (from the use of radioactive tracers) that the RNA in the nucleus is made there and is then transferred to the cytoplasm.

Now if the RNA is made on the surface of a 'chromosome molecule' the RNA might be able to copy *part* of the chromosome molecule. RNA molecules are known to be smaller than 'chromosome molecules' and unlike the latter can get out of the nucleus. The RNA molecules may be *messengers* carrying instructions from the chromosome molecules to the cytoplasm where the protein is made, carrying messages in a code written in chemical language which decides the order in which amino acids in the cell are to be linked together to make proteins.

The vitally important question which remains is, how do the amino acids 'know' which position to take on the messenger RNA? Or if you compare the code with Morse code, how is the translation from code to amino acid language done? If the signal . . . ——— . . . is to mean anything to us we must know that . . . is s, ——— is o. We need to have connected in our minds the sounds dot, dot, dot, with the letter s. Similarly, in the cell there needs to be some connection between code units and letters of the protein language, that is amino acids. If such a connection could not be found this elaborate theory would have to be discarded. Such 'translator units' have been found. It has been shown that in the cytoplasm small RNA units with small groups of code molecules A, C, G, are attached to particular amino acids. We may picture these units as follows:

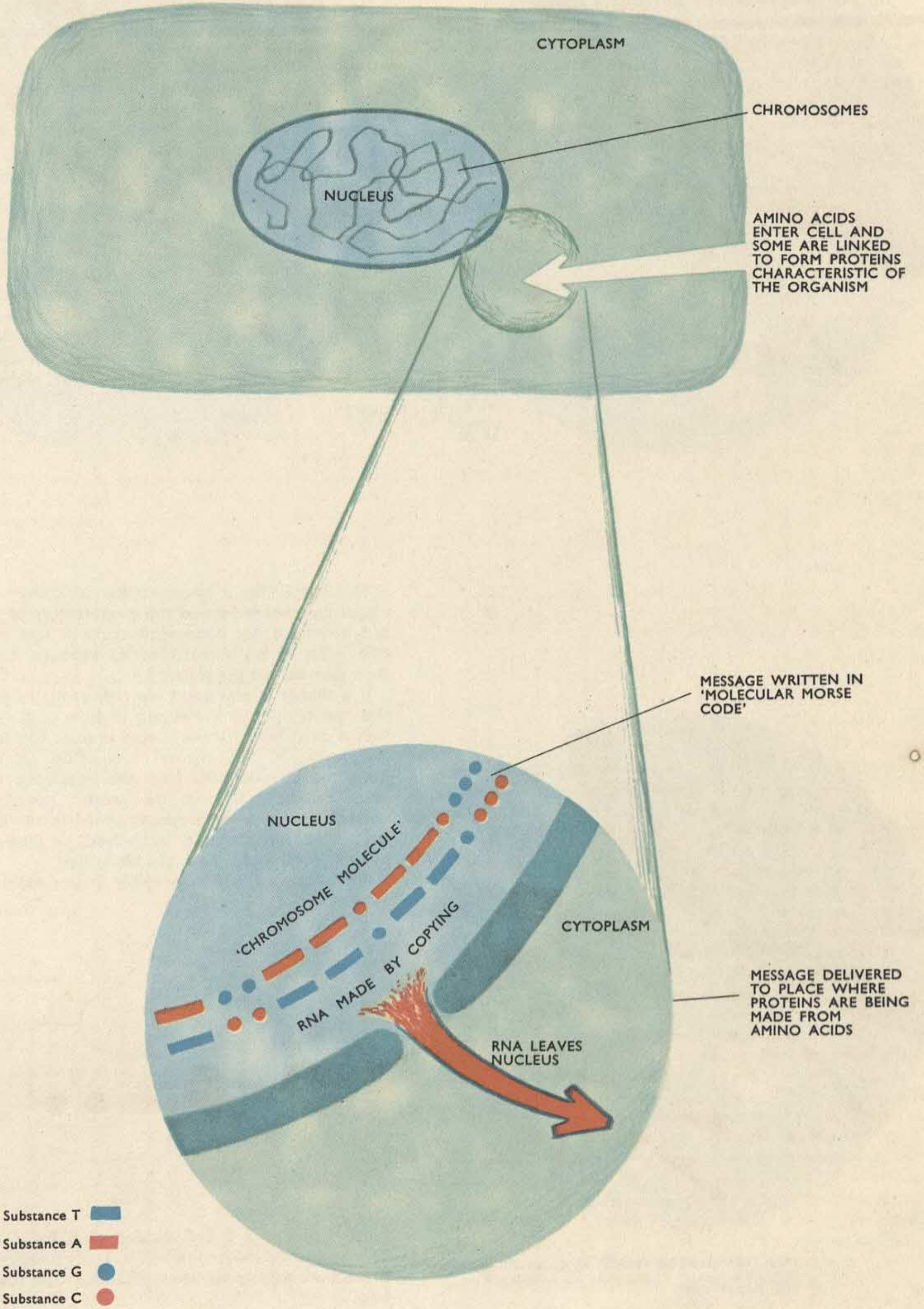




and visualise the theory of protein manufacture as in the following diagram.

* *In RNA there is also a substance U (uracil) in addition to A, C and G. This complicating feature has been deliberately omitted from the scheme of things presented here, since it does not affect the argument.*

A PICTORIAL REPRESENTATION OF THE THEORY CONNECTING CHROMOSOMES WITH PROTEIN MANUFACTURE



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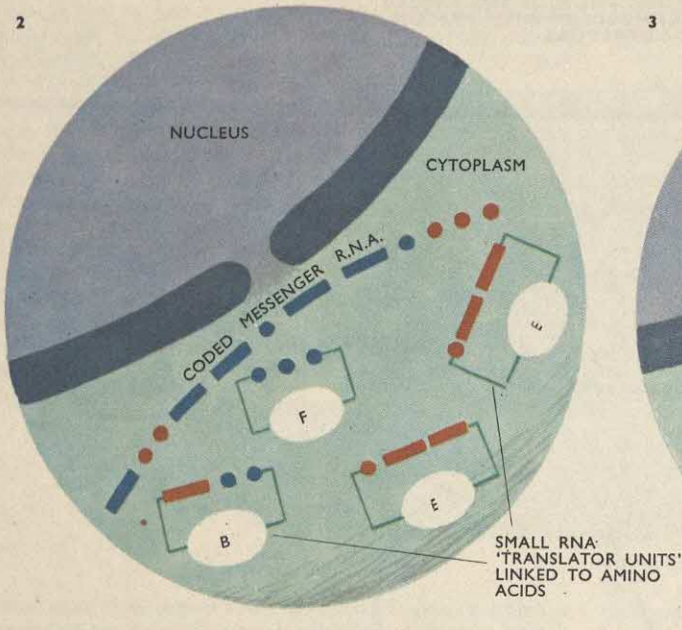

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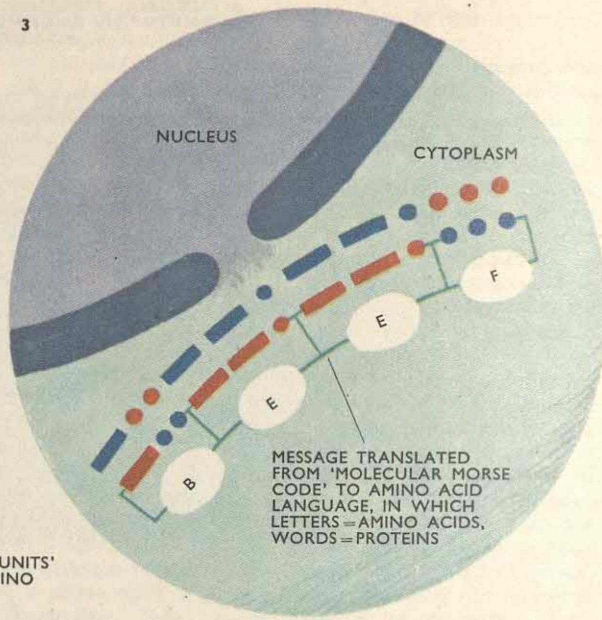
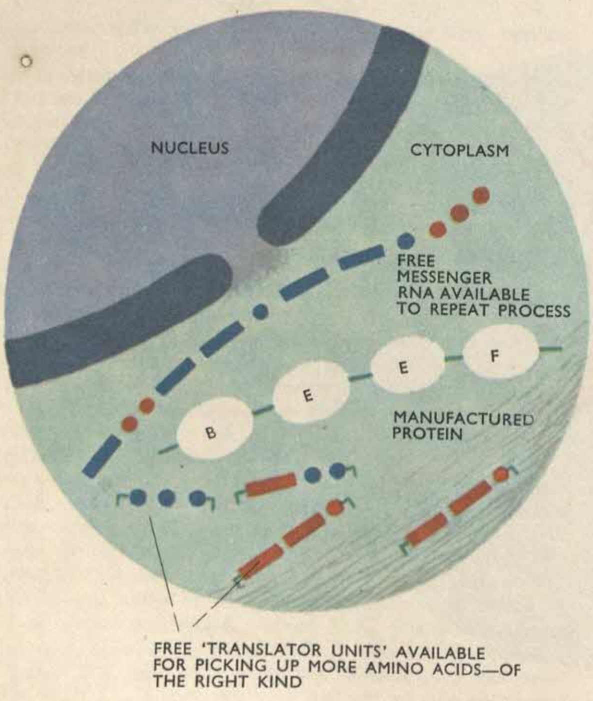
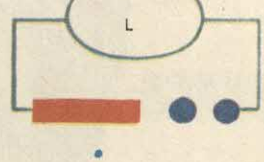




This theory fits a large number of known facts discovered about chromosomes and the manufacture of proteins in cells, but this does not necessarily make it fact, it may be a fairy tale. After all we invent theories because they fit facts. How then can we test the theory?

If a theory is any good we can use it to make predictions. We can say that if something is done to the cell then certain things must follow if the theory is true. This is exactly what is happening to this theory now. One splendid experiment done recently depended on the ingenious idea that if you were able to feed into the protein manufacturing process small RNA units the same as those in the cell **but with a different amino acid attached,** a protein perhaps very unusual for the species might be formed.

For example if it was possible in our imaginary cow cell to feed in



units a protein L-E-E-F instead of B-E-E-F would be made, on some of the messenger RNA. This turned out to be a correct prediction, and gives us confidence that the theory may be true.

3. Evolution

What are fossils?

Fossils are traces of animals or plants which have been naturally preserved in various ways, sometimes for many millions of years.

Many millions of years ago an ichthyosaur died and sank to the bottom of the sea. In time its skeleton was covered with mud, which gradually settled into solid rock layers. The encased skeleton was then slowly fossilized. At a much later date earth movements buckled the sea bed which consequently rose to become dry land. Then erosion by ice, water and wind slowly stripped off the rock, thus uncovering the fossilized skeleton.

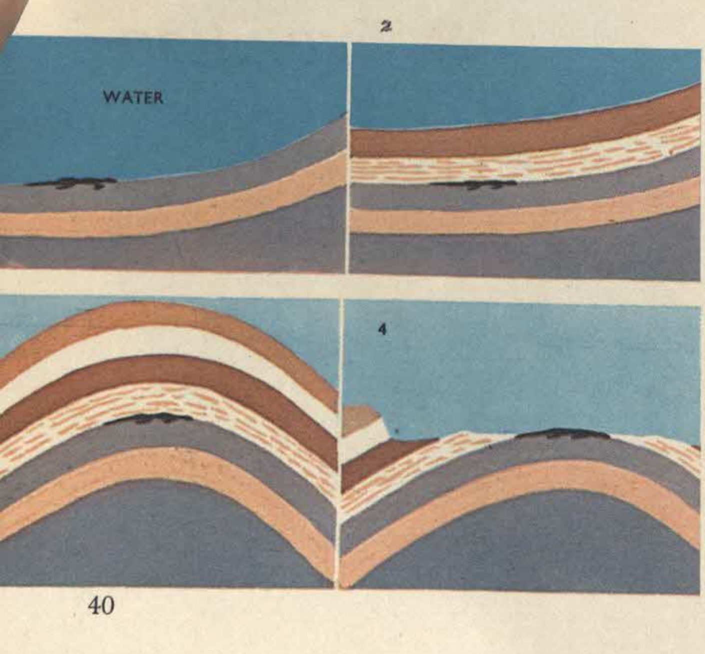
When an animal dies its body usually decomposes or is eaten by other animals. But the hard parts, the shell or bones and teeth, are not so easy to destroy. The essential conditions needed for preservation are that the animal should be buried relatively quickly, i.e. before the chemical and physical changes have time to reduce the bones to dust, and that the rock in which it occurs should escape severe changes by heat or pressure. The best conditions for preservation exist in the sea, especially near the coast, which is the reason why nearly all fossils are found in sedimentary rocks. Even fossils of land animals have been found in such rocks, probably through having been swept out to sea in floods.

Fossils take on a number of different forms. Very occasionally the actual skeleton may be preserved. This has happened where animals have been trapped in bogs or tar pits and quickly buried. The Californian tar pits, for instance, have yielded a wealth of skeletal remains; and under very unusual conditions the entire animal may be preserved. Mammoths (the forerunners of present-day elephants) have been found in Alaska and Siberia preserved almost intact in ice.

More often, however, the buried skeletons are *petrified*, i.e. replaced by stone. This is caused by ground water depositing mineral matter in the pores of the bones. On the other hand, each particle of the substance may be eaten away and replaced by a particle of mineral water. Petrified bones are usually produced by the former and petrified wood by the latter.

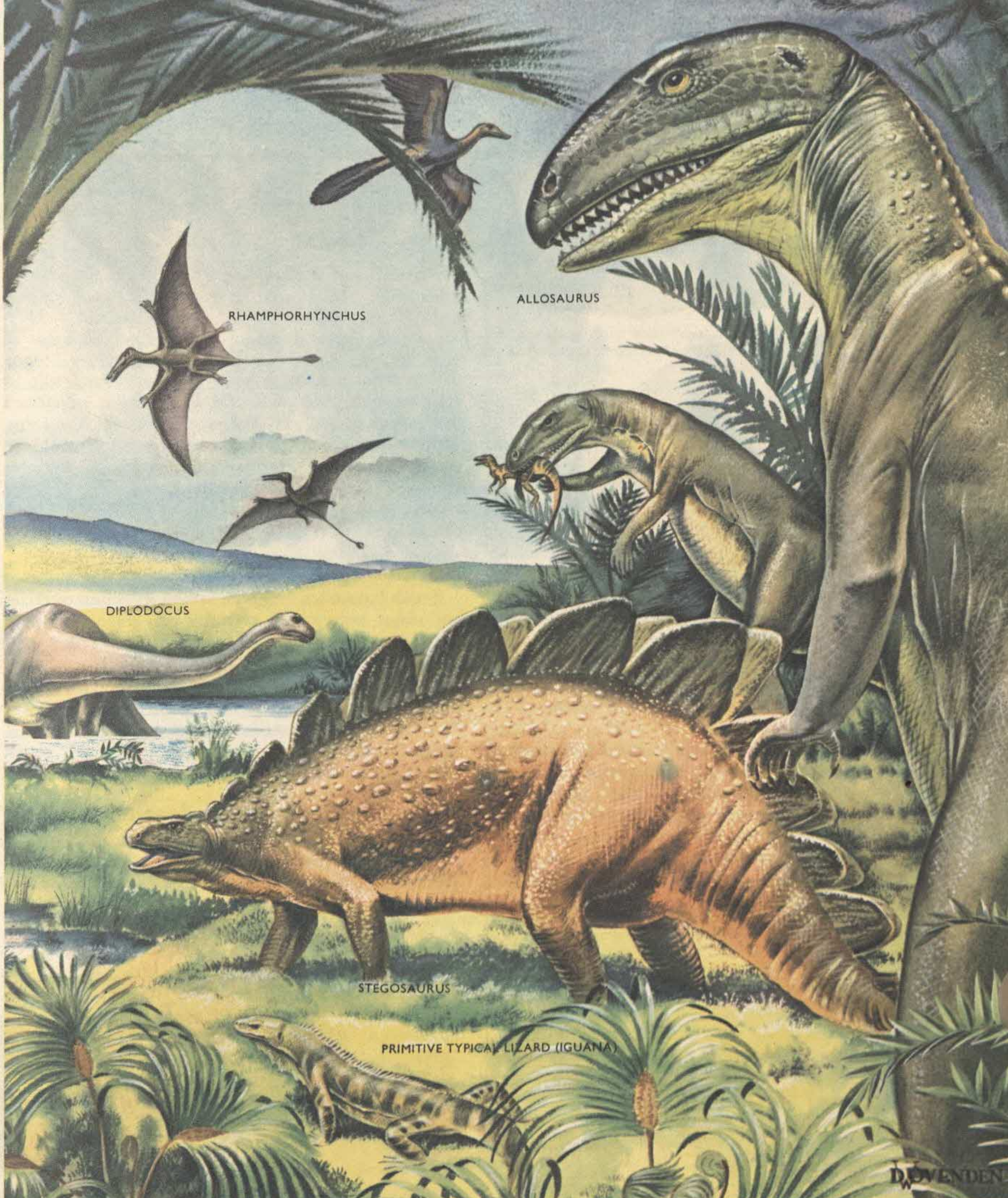
Some buried substances may be completely eaten away by percolating ground water, leaving a space in the rock corresponding to the original form of the object. This is known as a mould. Ground water may later fill this cavity with mineral matter, thus producing a rock cast of the object. Interesting moulds have been formed by insects becoming trapped in resin dripping from evergreen trees. This gradually hardens to form amber, and although most of the insect dries and withers away, the outline of its original form can clearly be seen from the hollow in the transparent material. Moulds of extremely thin objects, such as leaves, are generally spoken of as imprints.

Many plant fossils are simply residues of carbon which give the actual shape of the original object and fossils of soft-bodied invertebrate animals are occasionally formed in this way too. Sometimes the petrified skeleton of an animal may be surrounded by a film

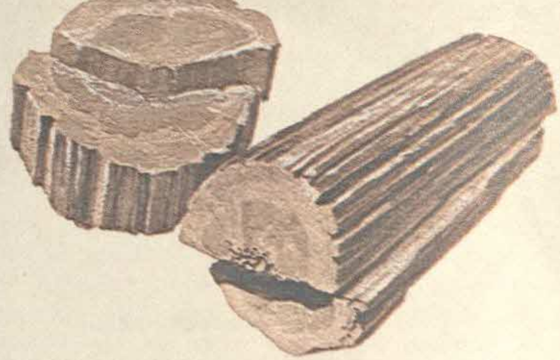


(Left) Diagrams showing the stages by which an animal may be fossilized and later discovered.

The fact that fossils of marine creatures, such as the ichthyosaurs which lived 150,000,000 years ago, may now be found in rocks high above sea level proves that the relative heights of land and sea have changed considerably throughout the past.



A composite scene showing various animals, that are known from fossils, in their natural surroundings. Allosaurus *was a Jurassic flesh-eating dinosaur. It is doubtful if* Diplodocus *ever left the water completely for its great weight would probably have been too much for its limbs to bear.*



(top left) A film of carbon shows the original outline of the ichthyosaur's body. (lower left) A footprint made in mud, which later hardened to solid rock, counts as a fossil. (right) One of the best examples of a petrified wood occurs in the Petrified Forest of Arizona.

of carbon which shows the actual fleshy outline of the creature as it was.

Unusual fossils are the tracks left by animals in mud which later hardened to become rock. Excellent dinosaur footprints, for instance, have been found by the side of an old water course in the Gobi Desert in Central Asia and in many other areas.

Fossils are a key to the past. They help to explain the changing pattern of life through the ages. But dating them can be difficult. Take, for example, a 100-foot-high chalk cliff. Geologists have calculated that it took 30,000 years for each foot of chalk to form. Thus a fossil found 30 feet above another would be 900,000 years younger than the one below. But this only gives their relative ages. Their actual age cannot be determined until the actual age of the chalk has been determined.

How are fossils found?

Fossils have often been unearthed in mines, quarries and other excavations, even by ploughing; but they have been exposed most frequently as water, wind, and ice wears away the land.

Once a large fossil has been found, the task of unearthing it, covering it in a protective coat of plaster for its journey to the museum, and cleaning, repairing, and piecing the bones together again may take a considerable amount of time.

What do we know from fossils?

Many fossils are the remains of animals and plants which are not found alive today. It is of course possible that some may yet be found alive just as a lung-fish

(centre) The Oligocene beds of the Baltic region of Germany have yielded good examples of insects encased in amber. (left) A cast of a trilobite formed by the later deposition of mineral matter in the mould. (right) A mould of a trilobite, the impression that may remain after the actual animal has disappeared.

Latimeria was caught off the east coast of Africa in 1939. This fish was thought to have become extinct several million years ago. However, it is unlikely that the larger dinosaurs have escaped notice, some were above 100 ft. long and weighed 20 tons, and the same must apply to many other animals and plants found only as fossils. Therefore, the first conclusion must be that some animals and plants which once lived on earth no longer do so.

Secondly, many animals and plants which are alive now are found as fossils even in the oldest fossil-bearing rocks. This applies especially to marine animals, such as some sea urchins. We must conclude that some animals have remained – so far as one can tell from fossils – unchanged for millions of years.

Thirdly, some animals alive now are not found as fossils. Also fossils of younger rocks are often not found in older rocks. For example, working from oldest to youngest rocks, fishes; fishes, amphibia; fishes, amphibia, reptiles; fishes, amphibia, reptiles and mammals are found (see illustration, above right).

It could be that the absence of reptiles and amphibia from the oldest rocks in this list is simply due to the fact that we have not tried hard enough to find them. It may be that the skeletons have not been fossilized.

But the most likely explanation is that there were no reptiles and amphibia at that time.

This leaves us with a very important question – *where did the amphibia and reptiles come from?*

Fourthly, it has been possible for some fossils to produce a series of similar structure, but of progressively more recent origin, in which small differences of structure add up to make the last in the series very different from the first. A vintage motor car is a very different 'species' compared with an E-type Jaguar, yet if we look at all the cars from vintage to modern we can recognise the small changes which have added up to make these two types of car very different. We may conclude that during long periods of time, some animals have changed progressively.

Moreover, just as the various kinds of present-day motor car are different, but nevertheless owe their origin to vintage cars, so it is with fossils. A group of basically similar fossils with some fairly obvious differences seem to be modified versions of older (vintage) animals.

These changes are called *evolution*.

Fifthly, the fact that the remains of tropical marine animals may be found for example 1000 ft. above sea level in the Pennines is evidence of climatic changes and earth movements.

From animal and plant fossils we have been able to build up a picture of the evolution of living things.

The absence of fossil amphibians, reptiles, birds and mammals from the early rocks is strong evidence for evolution.

Looking for fossils

Usually only the hard parts of organisms are preserved as fossils, for the soft parts soon decay away. Hard parts include shells, bones, teeth and spines. Occasionally the impressions of soft tissues may be obtained where the original object has been pressed into very soft sediments.

The rocks containing fossils are of three main types: sandstones which are gritty, shales which are softer and more plastic, and limestones which are usually hard. Sandstones are generally poor for fossil hunting. They are porous, and water can easily penetrate and dissolve away the minerals making the fossils. The fossils that are found are usually fragile. They should be gently treated and carried in small boxes filled with cotton wool or other shock-absorbent material.

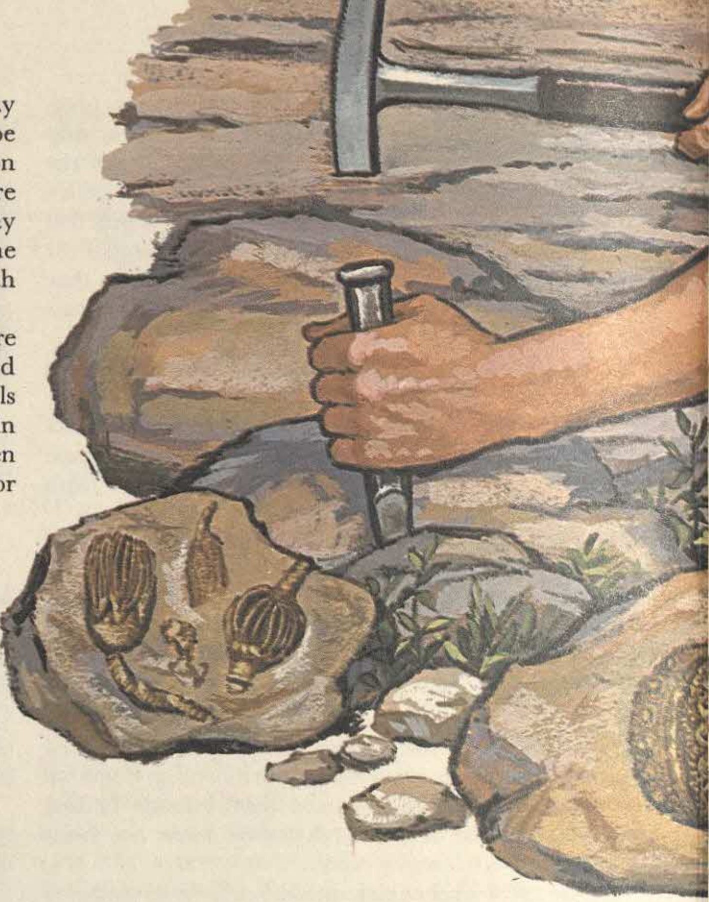
Shales are more rewarding, though sticky and unpleasant to work in. They are made of fine-grained clay minerals and are not porous. Water cannot percolate freely and the hard remains of buried organisms are not dissolved. Unfortunately shales are easily compressed and tend to shrink. Often this shrinkage causes the fossils to be squashed and flattened.

Shales may also contain nodules or lumps of limestone. Such nodules are formed by the calcium carbonate in the shale concentrating about a single nucleus. Often the nucleus is a fossil and cracking open a nodule may reveal a perfectly preserved specimen.

Limestones are often fossiliferous – in fact they are usually made up almost entirely of organic remains. Because the rock is so hard, it may be difficult to extract fossils without damage. The best place to look is in the broken fragments which collect at the bottom of exposed cliffs and quarries. These small pieces are easy to inspect and often processes of weathering clearly expose the fossils. Collecting from unweathered rock is hard work. Large slabs broken off frequently have to be further broken down before fossils are found.

Close examination of fossils, with a hand-lens, may reveal further information. Muscle scars may be preserved on the inside of shells, and growth lines on the outside may reveal the true age of the creature when it died. Comparison with similar present-day forms may suggest something of the conditions of the past, even such details as the temperature and depth of the sea.

Fossils may have been moved before they were finally buried. Those that have, are often worn and broken, particularly the valves which make the shells of bivalve molluscs. Others are still almost exactly in the same position as when they died. They have been left undisturbed on the sediment that formed the floor of the sea at the time.



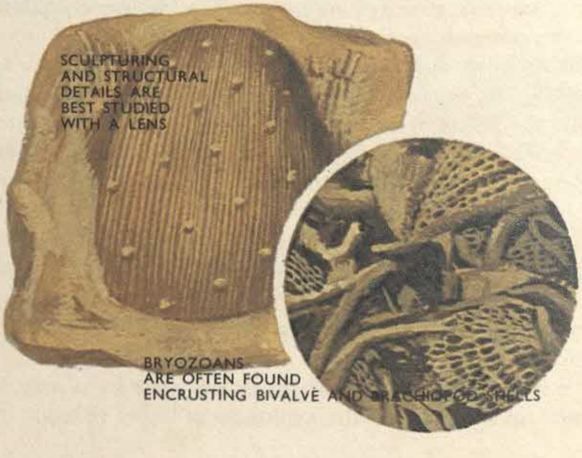
The use of a chisel avoids breaking or damaging fossils. Shallow stream beds particularly in clay country may be good places to hunt.

Little equipment is needed for collecting fossils. A hammer, a few cold-chisels of varying size, newspaper for wrapping the large fossils, and a number of small pill-boxes for holding smaller specimens. A notebook and pencil are useful for noting exactly the locality the fossils came from and, if possible, the exact layer of rock.

A convenient weight of a hammer is about 2 pounds – weighty, but not too tiring to carry about. Ordinary coal hammers can be used, though the all-purpose geological hammers are better. Apart from a flattened end for breaking off pieces of rock, they have a wedge-shaped end which can be used as a lever, a scraper, a chisel or a trowel.

Heavier fossils remain when lighter mud is washed away.

Inspection of a fossil with a lens shows delicate details of structure. Some small fossils may be found encrusting larger ones.



The Geological Time Scale

Rocks are the key to the past. To the geologist they are like the pages of a history book, though far more difficult to read since they may be torn, bent, upside down and scattered over a wide area. The geological time scale, based mainly on the record of sedimentary rocks, covers the span of the Earth's long history and allows geological events to be related in chronological order and given their correct positions in time.

Sedimentary rocks are those formed by the deposition of sediment beneath water. It stands to reason that a certain layer of sediment must be deposited before the layer above it and so must be older. It follows that when the rocks are raised above the sea you would expect any rock layer to be younger than the one it is resting upon. In many areas the layers have been twisted, ruptured and even overturned by earth movements. An even greater complication in drawing up the geological time scale is that no single region contains a complete record of the past. If it did, the thickness of the sedimentary rock covering would be something like one hundred miles. The fact is that deposition of sediment has always been going on in one region while the land is being eroded in another, just as it is today. Take, for example, the case of a region which has just been uplifted from the sea. The simple horizontal layers of sedimentary rock may be folded and squeezed into uplands by earth movements, and these will gradually be worn down by weathering and erosion to, say, a flat plain. At a much later date, the folds of the ancient uplands may once more be submerged beneath the sea and fresh layers of sediment laid down upon them. Then the whole region may later still be uplifted again to form dry land. It will now show a succession of rock layers, but these will not represent successive phases in the Earth's history; there may be a gap of many millions of years between the deposition of the older sedimentary rocks and the newer layers above. Fortunately, this time gap can be detected, for the newer, horizontal layers will appear to rest uncomfortably or unconformably upon the older, folded layers beneath. The surface of separation between the two is called an *unconformity*. Unconformities in rock layers always represent a gap in time. Since deposition must have been going on somewhere else in the world during this time gap (when the old uplands were being eroded) there must be rocks somewhere which will fill it. The great problem is how to recognise these intervening layers when they are found. This is where the value of fossils lies for the geologist.

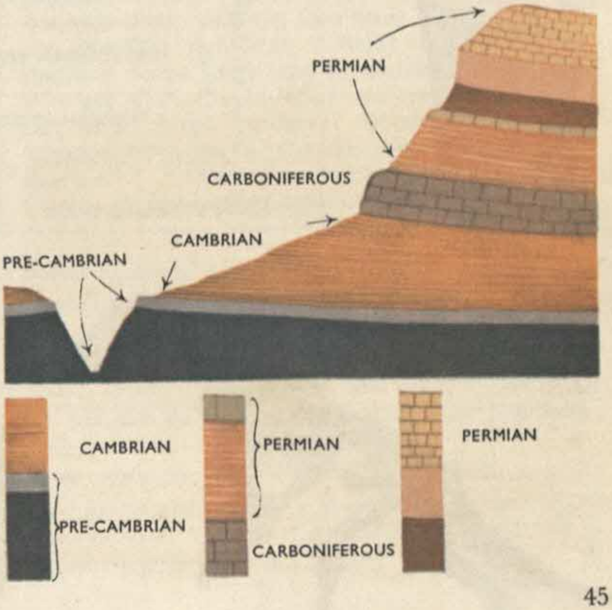
Fossil evidence

It was William Smith, the Father of English Geology, who first realised in the late 18th century that certain fossils were confined to certain rock formations. He reasoned that it should therefore be possible to identify a particular rock formation, wherever it was exposed, by the fossils it contained. The reason why certain fossils appear only in certain rocks could be explained

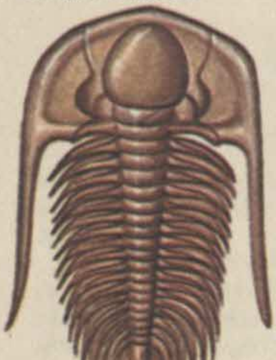
An unconformity in rock layers represents a time gap in geological history.

if life forms had evolved continuously throughout the Earth's long history. Thus if a single species of plant or animal is confined to a certain span of time its fossilized remains or traces will only appear in rocks laid down during that time. Thus the pattern of evolution

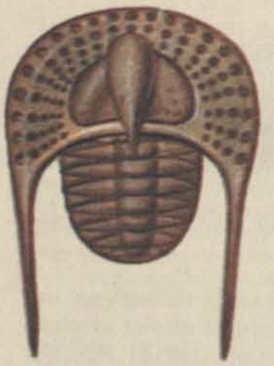
The Colorado river has exposed rock layers representing over 600 million years of the earth's history in forming the Grand Canyon, Arizona, U.S.A.



PARADOXIDES—A CAMBRIAN TRILOBITE



CRYPTOLITHUS TESSELLATUS—AN ORDOVICIAN TRILOBITE



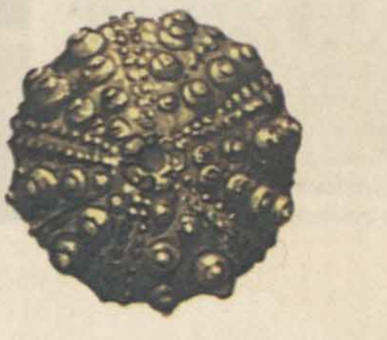
PENNSYLVANIAN CORAL

THE GEOLOGICAL TIME SCALE

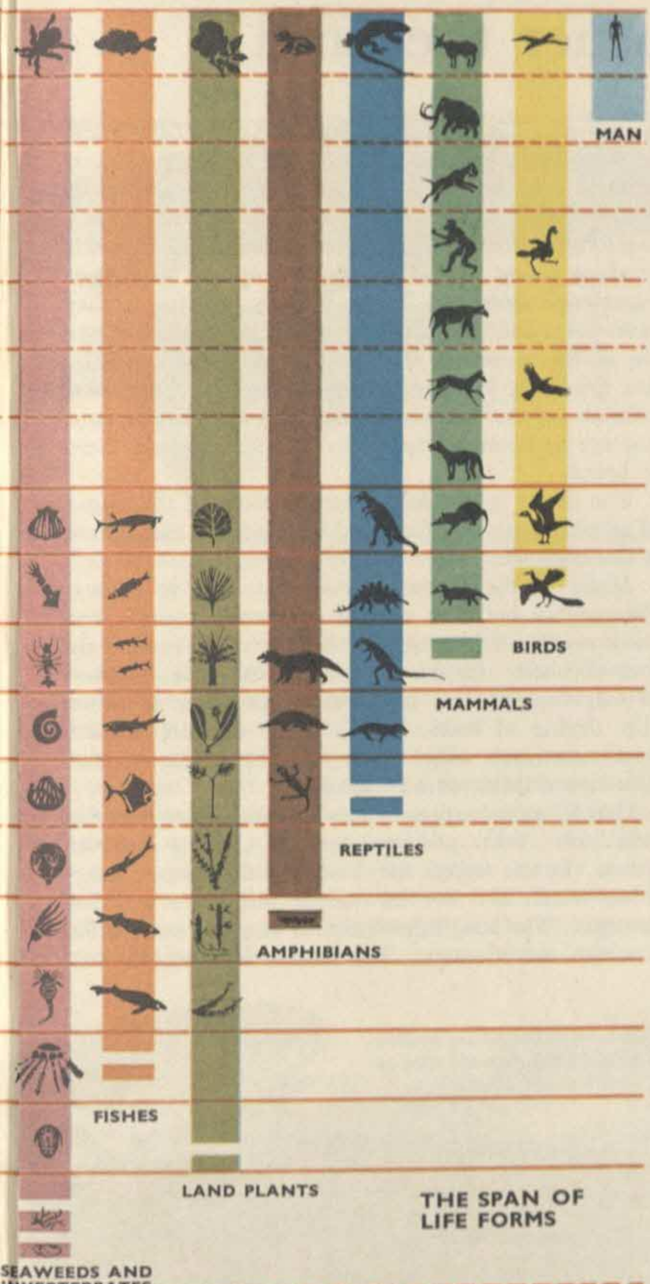
Eon	Era		Periods and systems	Derivation of names	Dates in years B. (before present)
PHANEROZOIC EON (*PHANEROS*=EVIDENT, AND *ZOON*=LIFE)	CENOZOIC ERA (*KAINOS*=RECENT)		**QUATERNARY PERIOD** THIS IS A CONVENIENT EXTENSION OF THE TERTIARY PERIOD AND MAY BE INCLUDED IN THE LATTER	RECENT OR HOLOCENE EPOCH (*HOLOS*=COMPLETE)	ABOUT 25,000
				PLEISTOCENE EPOCH (*PLEISTON*=MOST)	ABOUT 1,000,000
			TERTIARY PERIOD THE NAME RESULTS FROM AN OLD DIVISION OF STRATA INTO PRIMITIVE SECONDARY AND TERTIARY. THE NAMES OF THE SUB-DIVISIONS OF THE TERTIARY AND QUATERNARY PERIODS REFERS TO THE PROPORTION OF MODERN MARINE SHELLS OCCURRING AS FOSSILS IN THE ROCKS OF THAT AGE	PLIOCENE EPOCH (*PLEION*=MORE)	12,000,000
				MIOCENE EPOCH (*MEION*=LESS)	25,000,000
				OLIGOCENE EPOCH (*OLIGOS*=FEW)	40,000,000
				EOCENE EPOCH (*EOS*=DAWN)	60,000,000
				PALAEOCENE EPOCH (*PALAIOS*=ANCIENT)	70,000,000
	MESOZOIC ERA (*MESOS*=MIDDLE)		**CRETACEOUS PERIOD**	FROM *CRETA*=CHALK	135,000,000
			JURASSIC PERIOD	FROM THE *JURA* MOUNTAINS ON THE FRANCO-SWISS BORDER	180,000,000
			TRIASSIC PERIOD	FROM THE *THREEFOLD* DIVISION IN GERMANY	225,000,000
	PALAEOZOIC ERA (*PALAIOS*=ANCIENT)	UPPER	**PERMIAN PERIOD**	FROM THE *PERM* AREA OF RUSSIA, WEST OF THE URALS	270,000,000
			CARBONIFEROUS PERIOD *CARBON-BEARING* (COAL) — DIVISIONS RECOGNISED IN NORTH AMERICA	**PENNSYLVANIAN PERIOD**	305,000,000
				MISSISSIPPIAN PERIOD	359,000,000
			DEVONIAN PERIOD	FROM *DEVON* (MARINE SEDIMENTS)	400,000,000
		LOWER	**SILURIAN PERIOD**	FROM THE *SILURES*, AN ANCIENT TRIBE OF THE WELSH BORDER	450,000,000
			ORDOVICIAN PERIOD	FROM THE *ORDOVICES*, AN ANCIENT TRIBE OF NORTH WALES	500,000,000
			CAMBRIAN PERIOD	FROM *CAMBRIA*, THE ROMAN NAME FOR WALES	600,000,000
CRYPTOZOIC EON	**PROTEROZOIC ERA** (*PROTEROS*=EARLIER) **ARCHAEOZOIC ERA** (*ARCHAEOS*=PRIMEVAL) **EOZOIC ERA** (*EOS*=DAWN) (THE ABOVE ARE FORMAL ERAS)				THE CRYPTOZOIC EON EMBRACES ABOUT 80% OF GEOLOGICAL TIME

IGUANODON—A CRETACEOUS DINOSAUR

HEMICIDARIS INTERMEDIA—A JURASSIC ECHINOID



CERATITES CASSIANUS—A TRIASSIC AMMONITE



THE SPAN OF LIFE FORMS

Calibrating the Time Scale

The geological time scale gives the relative ages of geological events. It indicates that the vast swampy forests, from which the world's great coal deposits are derived, flourished after the Old Red Sandstone of the Devonian Period had been laid down and prior to earth movements which resulted in the uplift of the Appalachians of North America, a range of mountains which probably rivalled the present Alps in height. But it does not indicate the absolute age of the Coal Measures, nor the Old Red Sandstone.

It was only the discovery of radioactivity in the closing years of the last century that paved the way for calibrating the geological time scale fairly accurately and thus converting geological or relative time into absolute time. Certain rocks can be dated by the radioactive minerals they contain. For radioactive elements, such as uranium and thorium, gradually break down or decay into more stable elements (in these cases lead). Since the rate at which this happens can be calculated, it is possible, by noting the amount of lead produced at the expense of uranium or thorium in such rocks, to determine their age. In practice this is more difficult than it seems, for one gram of uranium will yield just 0.000136 gram of lead in one million years. So, a very small error in assessing the uranium/lead ratio means an error of many millions of years in the final calculation of the age of the rock.

Nor is this the only problem, for, generally speaking, radioactive minerals are found in igneous rocks and it is often difficult to date these geologically. If the particular igneous rocks happen to occur as a lava flow in sedimentary rock layers then they can easily be dated geologically by the strata immediately above and beneath them. But say they have resulted from the injection of molten material into the sedimentary rocks from below: certainly they are younger than the invaded sedimentary rocks, but how much younger? When the dated igneous rocks can be related closely in age to the associated sedimentary rocks they act as markers in the geological time scale.

is clearly recorded in successive rock layers which have not been greatly disturbed and it is possible to recognise rocks in one region as filling in a time gap in another region by the fossils of transitional life forms they will contain. And an apparently unnatural sequence of fossils will also show rock layers which have been overturned.

Thus, with the aid of fossils it has been possible to build up a record of the rocks of various ages arranged in chronological order (the geological column) and to draw up the geological time scale.

FOSSIL BARK OF *LEPIDODENDRON*—A CARBONIFEROUS SCALE TREE

Vertebrates conquer the land

It is possible to piece together the evidence from rock structure and formations and from fossils and provide an imaginary picture of changes which took place involving land, climate and life. There follows an account of the Devonian period, dated about 400,000,000 years ago, based on the evidence available. The story is built up in the same way as a detective might build up an imaginary picture of how a crime was committed – the story fits the evidence. It is not the only possible story.

Earth movements and mountain-building at the end of the Silurian period have resulted in the lifting up of large areas of sea-bed, especially in the Northern Hemisphere. The new land is traversed by rivers and streams and dotted with lakes and swamps. This is the Devonian period. As yet, the land surface is quite bare; only a few plants are to be found there. Life is centred in the waters of the rivers and lakes where numerous fishes swim. Some of these fishes are heavily armoured and have no jaws. They feed by sucking up mud from the bottom and extracting food. Other fishes have jaws; they are less heavily armoured and swim freely in the waters. There are two main groups – those with ray fins and those with fleshy-lobed fins.

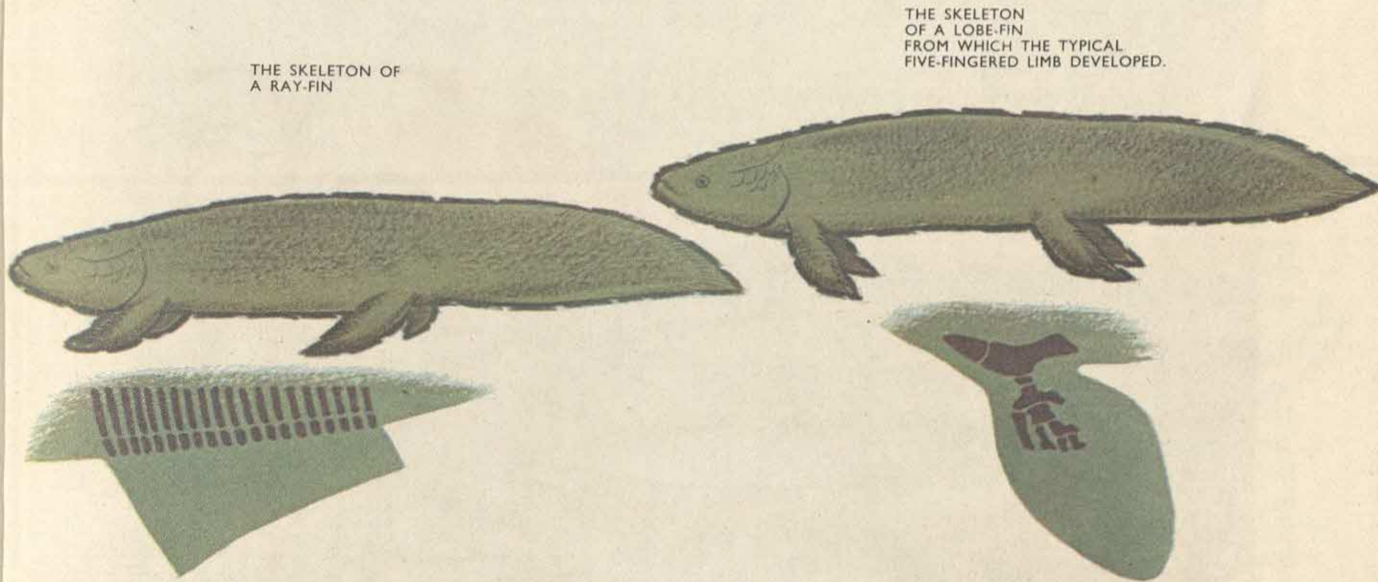
The climate is mainly warm and dry: rivers and lakes periodically dry up. Many fishes are stranded or die through lack of oxygen in their shrinking lakes. But the fishes with lobed fins survive because they can gulp air into their air-sacs, which act as lungs. They can also move about on their fins and perhaps find plenty of food in the form of dead and dying fish. Some of these animals actually leave their drying pools and wander over the land in search of new stretches of water. Many of them die, but those that can survive the longest may find water and continue to live and produce young. These young grow up and sometimes experience drought. Their drought-resisting ability saves them and the race continues to exist. Very slowly the ability to survive and move on land improves: the fins gradually become modified into legs. The new animals are the first amphibians. They can live on land but are at home in the water and must return there to breed.

The above is a widely accepted *theory* of the origin of amphibians – the first land vertebrates – but where is the evidence?

Many of the Devonian rocks are red in colour. Present-day hot, dry regions frequently contain red sands and it is fair to assume that Devonian rocks were formed under mainly dry conditions. The presence of salt deposits also indicates evaporation of water (i.e. drying of lakes, etc.). These deposits contain numerous fossils which show that the ray-finned and lobe-finned fishes were common.

Careful examination of some fossils shows that the lobe-finned fishes possessed air-sacs opening into the throat. In this respect they resemble the modern lung-fishes which also live in regions subject to seasonal drought. The lung-fishes gulp air and can survive for a while out of water. The Australian lung-fish can

In open waters, the ray-finned fishes were able to compete successfully but when the waters became shallow and crowded, the lobe-finned fish were at an advantage. They could breathe air and when the water dried up they could probably survive. This type of animal evolved into the primitive amphibians as above.

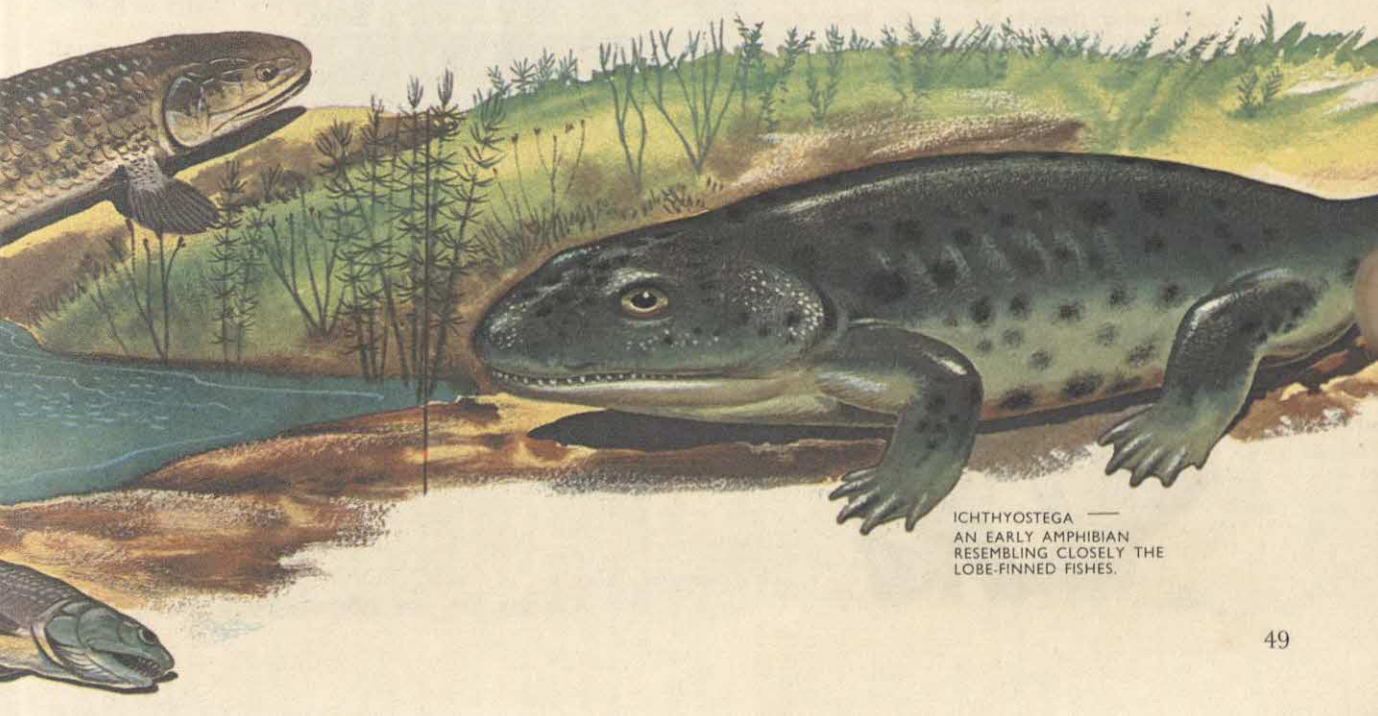


The Australian lungfish can crawl about on the mud and this supports the theory of amphibian descent from lobe-finned fish. The bony skeleton of the lobe-fin (right) is very different from that in the fins of other fishes.

use its fins to crawl about on the mud. It is reasonable to expect that the ancient lobe-finned fishes behaved in this way. This sort of evidence strongly supports the theory of the origin of amphibians.

More evidence in favour of the evolution from lobe-finned fishes comes from the Upper Devonian rocks of Greenland. Here, there are some remarkable fossils, believed to be about 350 million years old. The bones of the skull and of the spinal column show striking resemblances to those of the lobe-finned fishes. Such features as five-fingered limbs and strong limb girdles, however, are definite amphibian features. These animals (e.g. *Ichthyostega*) certainly merited the term 'missing link', although they are not thought to be the actual ancestors of modern amphibia. There is, then, a wealth of evidence showing how the amphibians probably arose.

Remains in the Devonian and Carboniferous rocks indicate that, for many millions of years, the amphibians remained fish-like, although the limbs were developing into the typical five-fingered form. Gradually, the more terrestrial types evolved. The skeleton and, probably, other features became more suited for life on land. The amphibians, however, never came



A typical Devonian scene with drying pools and marshes. The plants are known from fossil remains. That the land was dry is known from the red rocks and beds of salts deposited by evaporating water.

to dominate the Earth in the way the reptiles did later. The amphibians were tied by the fact that they could never completely escape from the water. Even the present-day frogs and toads have, with few exceptions, to return to water to breed. The young stages (tadpoles) live in water and breathe with gills in much the same way as fishes.

The living amphibians make up only a small fraction of the modern animal world but they are far from being 'surviving relics'. They are highly specialised animals well adapted for the lives they lead. A modern frog is different indeed from its primitive Devonian ancestor.

At some point way back in time a group of amphibians developed a more waterproof covering and began to lay eggs that could survive on land. These animals were the ancestors of the reptiles which came to dominate the Earth during the Mesozoic Era (Middle Life Age), between one and two hundred million years ago. Other groups of early amphibians gave rise to the ancestors of modern forms, while a great many of them died out at the end of the Palaeozoic Era.

(*left*) *A modern frog, very different from the early amphibians.*

A brief history of the plant kingdom

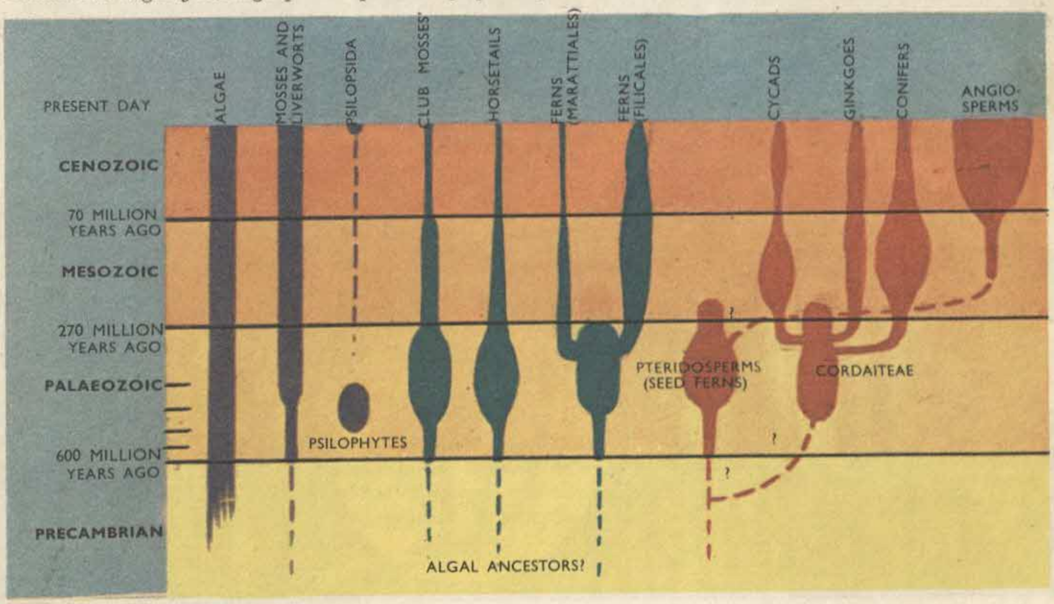
SUNLIGHT 2,000 million years ago was being used by plants just as it is used today – for building simple chemical substances into complex foods. Only traces of these very ancient plants are preserved in the rocks. They were all probably *algae*, very simple water-dwelling plants. Algae, unlike most land plants, have no water-proof outer coating (*cuticle*), nor do they develop special tissue (*vascular* tissue) for transporting water and foodstuffs.

About 600 million years ago, the remains of animals suddenly became more numerous in the fossil record. This was the start of the Cambrian period. There are also a few remains of plants. Surprisingly, these remains are not of the simple, water-dwelling algae. Instead there are specialized vascular (woody) tissues and wind-blown spores with outer cuticles. Several groups of land plants seem already to have emerged – mosses and liverworts (*Bryophytes*), spore-bearing plants such as today's ferns, club mosses and horsetails (*Pteridophytes*), and seed ferns (*Pteridosperms*). Early *Gymnosperms* (seed-bearing plants) may also have been present. How these groups arose, it is difficult to say. There is no fossil evidence. But certainly plants must have invaded the land long before, in Pre-cambrian times. Perhaps each group evolved from a different group of algae and had solved the problems of living on the land in different ways. There seems no reason why vascular tissues, cuticles, secondary wood, leaves and roots should not evolve more than once independently.

Another gap follows, with no more plant remains. Then in Silurian rocks 400 million years old there are found the *Psilophytes* – simple land plants with vascular tissue but no distinct leaves, roots or stems. Psilophytes were the first land plants discovered and for a long time have been thought the undoubted ancestors of all other land plants. But more highly developed land plants are now known to have been living 200 million years before. It seems likely that psilophytes are only the survivors of some earlier primitive stock.

But if higher plants were in existence in Silurian times where is the evidence? The only fossil preserved is a leaf of a club moss (a pteridophyte). The discrepancy seems due to the different localities of plants. The psilophytes inhabited low mud flats near the water; there was always a strong chance that the land would sink and the plants be preserved under the invading water. The more advanced land plants probably lived inland, on higher ground, where surroundings were more varied. The chances that they would become buried with sediment was much less

A chart showing the sequence of the main plant groups in geologic time. Because of an incomplete fossil record the evolution from one group to another is uncertain. The origin of the angiosperms is particularly open to question.



likely. However, in following Devonian times battered logs have been preserved in marine sediment as though carried by rivers into the sea.

The Carboniferous period followed and in coal seams over 300 million years old the first really extensive picture of plant life on land is given. Coal is the fossilized remains of swamp forests of the time. Considerable evolution must have taken place over the millions of years since the Cambrian period. The pteridophytes, pteridosperms, and the gymnosperms had become varied.

Amongst the pteridophytes there were relatives of today's horsetails. But these forms were not small and delicate like our present species. They stood up to 100 feet high and had woody trunks. But they possessed some features in common with today's forms – stems with lengthwise ribbing, and points along the stem (*nodes*) bearing whorls of leaves. The club 'mosses' (*lycopods*) were also large and woody.

Amongst the gymnosperms, a group called the *Cordaitales* were the most numerous. They formed large woody trees. The cordaitales became extinct in Permian times but probably gave rise to all later gymnosperms.

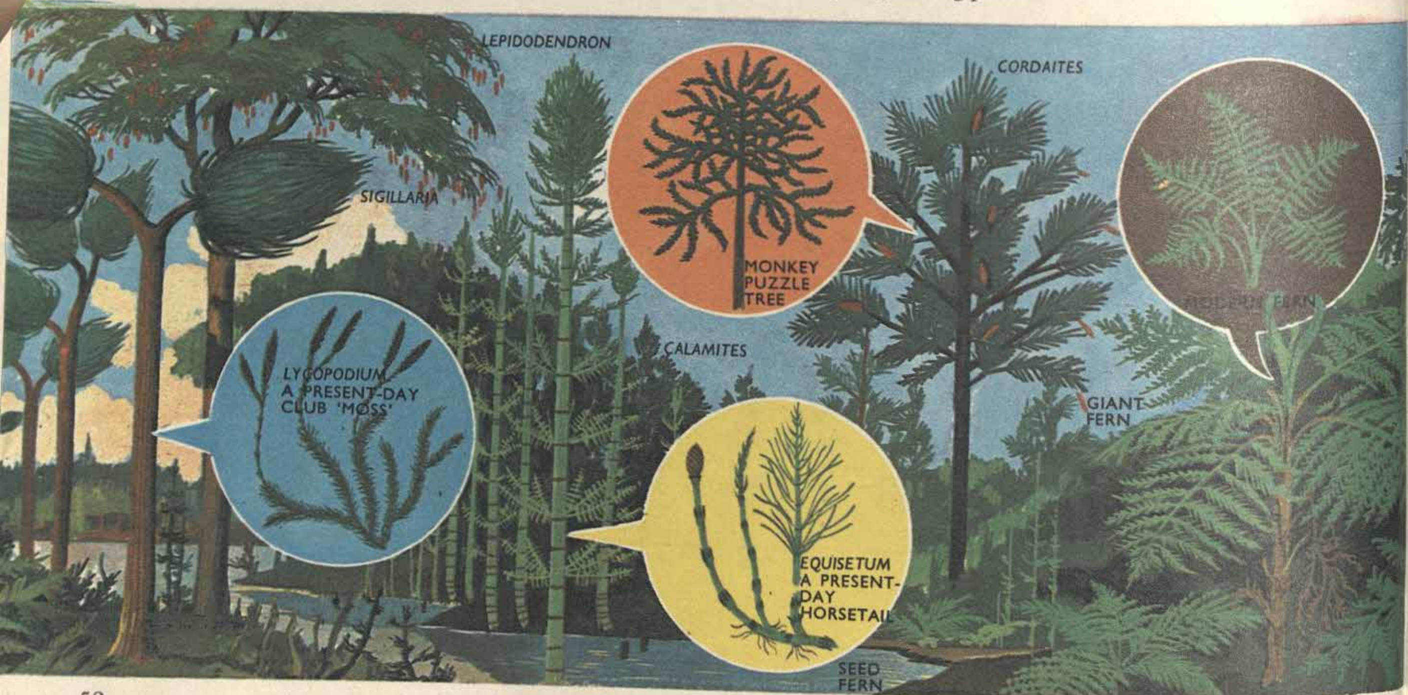
The most important group of today's gymnosperms are the conifers. Conifers increased in number towards the end of the Carboniferous period. Today the group is represented by such forms as the monkey puzzle tree, the pine and larch, the juniper and cypress and the yew. Other groups of gymnosperms living today are the *Cycads* – trees with stout unbranched stems, and a crown of large fern-like leaves. They first became prominent in Jurassic times. Related to the cycads is the maiden-hair tree (*Ginkgo*). The group of plants to which it belongs stretches back to late Carboniferous times.

Also amongst the Carboniferous fossils recovered are numerous pteridosperms (seed ferns). They looked like ferns yet bore seeds instead of spores. They survived until Cretaceous times and then became extinct.

Possibly they are the ancestors of the last great group of plants to appear – the *Angiosperms* or flowering plants.

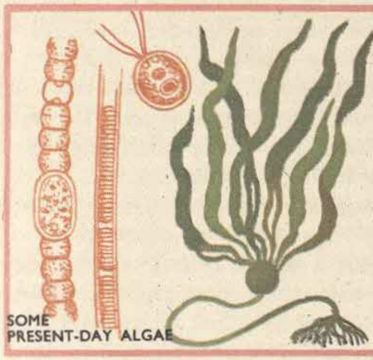
Angiosperms first appeared in Middle Cretaceous rocks 120 million years old. They were already quite varied. They include forms very similar to many of the present-day magnolias, oaks and poplars. They very rapidly became the dominant group of plants. In the face of this vigorous competition many old groups of plants declined.

The sudden emergence of the angiosperms as an already varied and distinct group is probably due to poor preservation in the fossil record. Again it seems

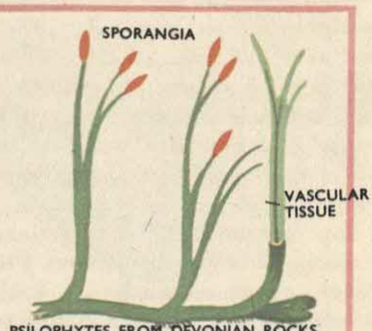


A carboniferous swamp-forest 250 million years ago. There were no flowering plants but the other main branches of the vegetable kingdom had emerged. The soft-tissued club 'mosses' that survive today are relatives of the ancient scale trees Sigillaria and Lepidodendron. The counterparts of our spindly horsetails were woody and some stood 100 feet high. Cordaites was an ancient gymnosperm and seems a particularly close relative of today's Monkey Puzzle tree. Ferns covered the ground; some grew into shrubs or small trees. In structural details, most of them differed from today's ferns. Seed ferns were small but numerous. Perhaps they were the ancestors of the flowering plants.

likely that early evolution took place on high ground where there was little chance of remains becoming fossilized. Perhaps the angiosperms stretch back as far as Permian times.

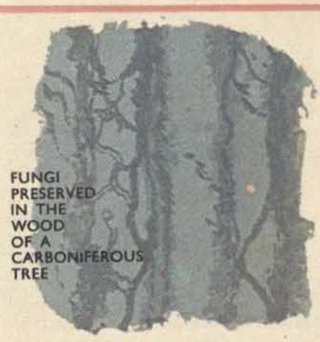


The first plants probably resembled our present-day algae. They lived in the sea and had no vascular tissue or cuticle. Perhaps most of today's groups of land plants descended independently from algae. They would have passed through a simple stage resembling the primitive fossilized *Psilophytes*.



Seed ferns looked like ferns but bore true seeds like gymnosperms and angiosperms. They were abundant in Carboniferous times but died out in the Cretaceous period. Their seeds were enclosed like the angiosperms – not borne naked on cones like the gymnosperms. Perhaps they were the ancestors of the angiosperms.

Mosses and liverworts have very delicate tissues which are rarely preserved in the fossil record. They are however very ancient groups, and probably date from Cambrian times.

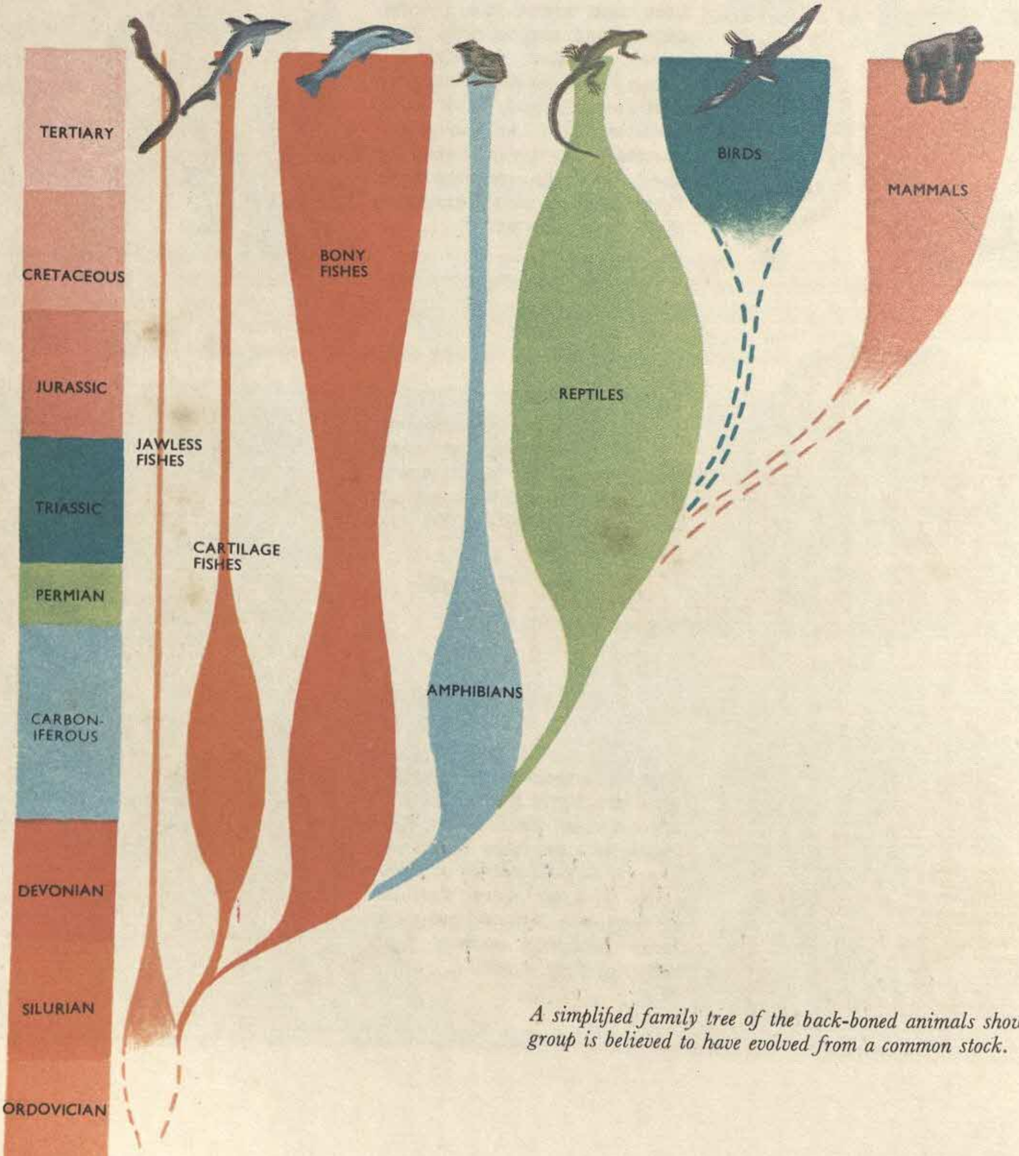


The fossil remains of fungi are also rare. From the little that is known about their history, there seems to have been hardly any change in their habits or structures at least since Carboniferous times. Different groups of fungi probably evolved from different algal ancestors.

The case for Evolution

THE idea that living things have *evolved* (i.e. present-day organisms have developed from previously existing organisms) is quite ancient and was first put forward by the early Greek philosophers. It has, however, always been opposed to a greater or lesser extent by the supporters of the theory of *special creation*. These people hold that the many kinds of animals and plants were created by some supernatural force and have continued without alteration. Cuvier, the famous French biologist (1769–1832), examined numerous fossils and found that most of them were types no longer living. This led him to the theory of *Catastrophism* in which he stated that there had been several special creations throughout the Earth's history and that each had been wiped out by some further catastrophe. The theories of special creation still have their supporters but have now been discarded by the scientific world. Evidence collected from various branches of biology has been put together to form what is known as the general theory of evolution. The evidence is not indisputable but the theory is the one that best fits the available facts.

Evolution implies the gradual change of one species into another. Such changes have now been observed in a few cases. This is especially so in the case of domestic and farm animals where new and improved varieties have been produced by artificial selection. The almost sudden appearance of dark (melanic) forms of various moths in recent years is a good example of natural change (see page 58). There is no reason to suppose that such changes in the past could not have given rise



A simplified family tree of the back-boned animals showing how each group is believed to have evolved from a common stock.

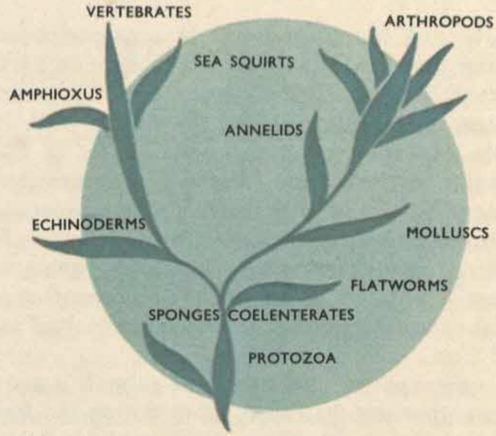
to new and distinct species in time.

The aim of classification is to group those animals that have a number of characteristics in common. The largest group is the phylum and its members all have a basic similarity. It is reasonable therefore to assume that the members all arose from a common ancestral type. The phyla themselves can be placed in some sort of order from the most simple to the most complicated but there are large gaps in the arrangement of present-day forms. These gaps may be filled when more fossils are known, but at present we cannot say for certain whether, for example, starfishes and insects had a common origin or whether they have evolved from independent beginnings.

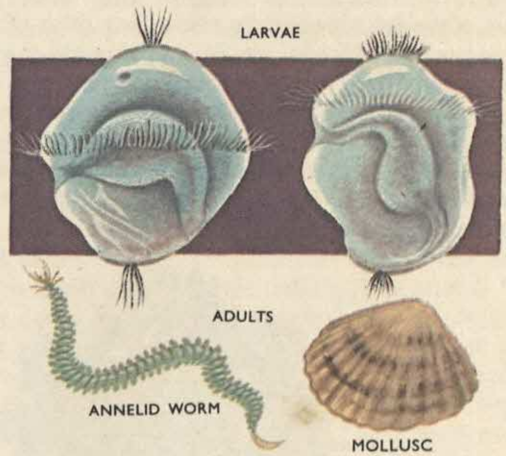
Animal structure, too, provides evidence of evolution. The fins of a lung-fish, the wings of a bird and the forelimbs of a dog are superficially very different but all arise from a similar part of the embryo: they are *homologous* structures. Internally, common bone patterns can be seen. These limbs therefore represent modifications of a basic type and point to evolution from a common ancestor.

In the nineteenth century, the *Recapitulation* theory was put forward. This suggested that, during development, an animal passed through stages resembling those of its evolutionary history and it was presented as support for evolution. The embryos do pass through various grades of development but cannot be said to resemble first a protozoan, then a coelenterate, and so on, as the early supporters of the theory believed. The similarity between early vertebrate embryos is very striking and this, together with other evidence, makes it quite probable that these animals originated from a common stock. An interesting similarity between different phyla is the existence of a particular type of larva in both molluscs and annelid (ringed) worms. This larval type is called the trochophore. It is possible that molluscs and worms originated from a common ancestor that had a larva of this type.

The greatest volume of evidence for evolution is provided by fossils, but here again the emphasis is on evolution within the major groups. The fossil record is very incomplete and almost non-existent before Cambrian times. At the beginning of this period most of the major groups were already in existence and we have no proof that the lower forms gave rise to the more advanced groups. Within the phyla, however, fossils show very clearly the evolution of new species. In

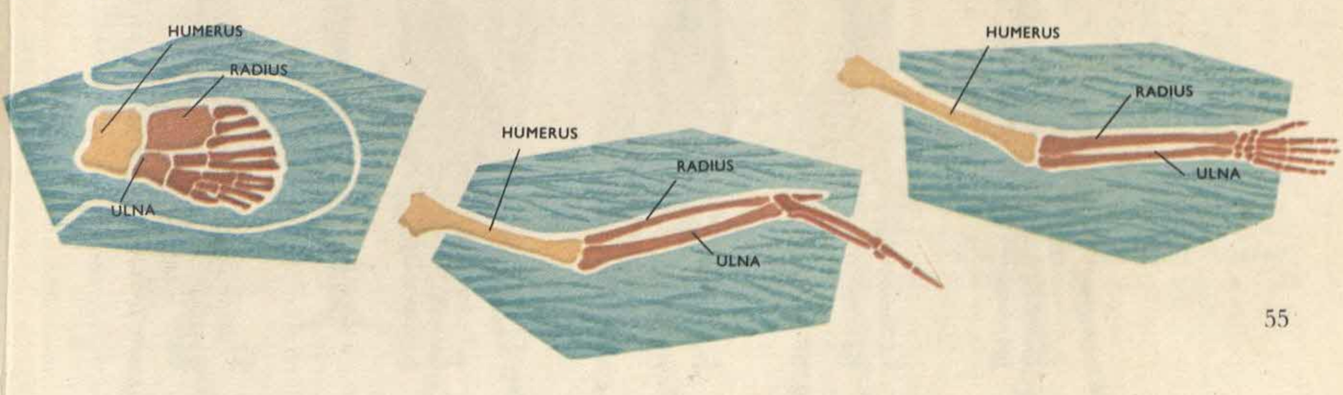


A possible evolutionary tree of the invertebrates. Most of the connections are merely theoretical.



Evidence that molluscs and annelid worms had a common ancestor is provided by the existence of similar larval forms in some species.

The basic similarity between the limbs of a lung-fish, bird and Man indicate a common origin. This sort of evidence strongly supports the theory of evolution.

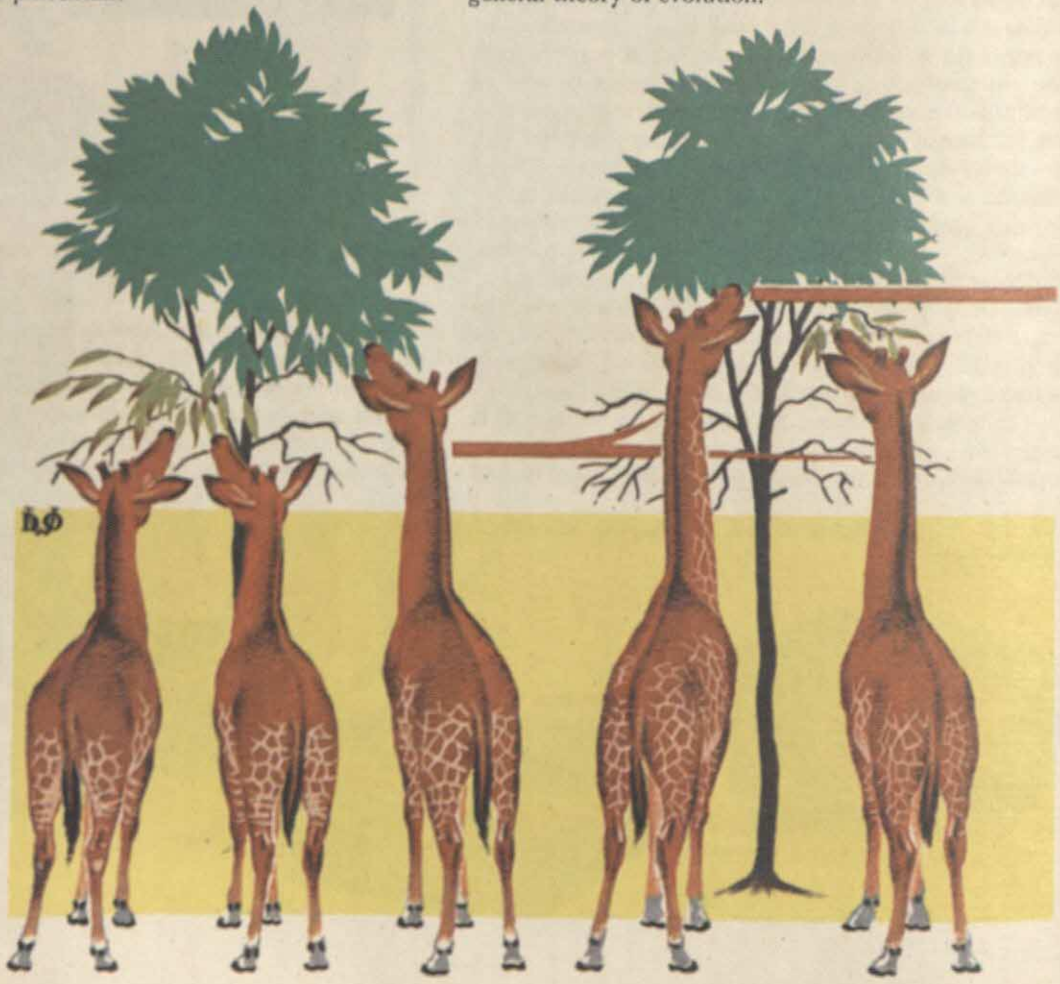


successive rock layers the fossils become progressively more and more different until a new specific name is warranted. The vertebrates show a fuller fossil record than most of the invertebrates, for animals with hard skeletons are well suited for preservation as fossils. Within the vertebrate group – as with the other phyla – the generalised forms gave rise to the more specialised and advanced ones. For example, the fishes arose from primitive, jawless creatures and radiated into several branches. It is probable that one of these branches gave rise to the amphibians which themselves evolved along several lines.

The geographical distribution of animals is another feature supporting the theory of evolution. In fact, it was by studying this that Darwin hit upon his theory of *Natural Selection*. Where any region, notably an island, has been separated from neighbouring parts, its animals, although superficially resembling those of the mainland, often differ in detail. The changes can be explained most easily by the fact that evolution has taken place. Australasia's native mammals are all egg-laying or pouched creatures. Presumably this whole region was separated before the placental mammals arose and in this region evolution did not follow along the line to the placentals.

Darwin visited the Galapagos Islands in 1835 and was struck by the variation among the birds and other animals. Although the islands are not very far apart, each has a distinct assemblage of bird species. This could be explained only on the basis of change since the birds first arrived, for it was highly improbable that one species arrived on only one island. Being isolated on each island, the birds were free to evolve in different directions and produce several different species. Darwin realised that this was the case and sought to find a method whereby this could have happened. He sought for it for a long time and many years later published his theory of Natural Selection.

We thus have a wealth of evidence to support a general theory of evolution. There is no direct evidence that life was created only once or that the various major groups are related, although similarities, such as that between young annelids and young molluscs, suggest that this might be so. There is direct evidence for the evolution within a group from simple to advanced forms and it is possible therefore that such evolution has taken place between the groups too. Until further fossils are found we cannot be sure but the evidence available supports, on the whole, the general theory of evolution.



How Evolution Works

It is widely accepted that living things evolve. One species gradually alters and gives rise to others. How does this come about? This question puzzled Charles Darwin, the great naturalist, for many years. He firmly believed in evolution but for a long time was unable to explain it. After many years he produced his celebrated theory of Natural Selection – a theory based on the wonderful ways in which animals are adapted to their surroundings.

Long before Darwin's theory appeared, however, another theory of evolution was put forward. This was developed by Lamarck, a French scientist who lived from 1744 to 1829. According to his theory, if a man trained hard for athletics and built up powerful muscles, his sons would also have strong muscles. In other words, characters acquired during a lifetime could be inherited. It is certainly true that constant use of muscles strengthens them and that an unused muscle deteriorates but there is no evidence whatsoever that these features are inherited.

This theory gives no indication of how new structures arise. It implies that an animal develops a structure because it needs it. The classic example is that giraffes grew longer necks in order to reach the higher branches. It has not been possible to support Lamarck's idea that acquired characters can be inherited, so that his theory is not widely accepted. The body cells are quite separate from the reproductive cells and only the latter pass on to the next generation.

Darwin's theory was published in 1859 as the famous 'Origin of Species' although he had previously lectured on his findings and those of Wallace who arrived independently at a similar theory at about the same time. Darwin witnessed the 'struggle for existence' among animals. Most of them produce many offspring but only a few survive. The others succumb to predators, disease and starvation: in other words there is 'survival of the fittest' (fittest meaning best fitted to the demands of the environment). Darwin also noticed that individuals of a species all vary slightly. All human beings belong to the same species but almost every one can be distinguished by the shape of the ears and nose alone! Such variations make some animals more suited to their surroundings than others. Those best suited are more likely to survive and to reproduce and therefore *if* the favourable variations are passed on to the next generation the species will gradually change in time. In this way an animal species becomes ideally suited to its surroundings. The latter are always changing, however, and so natural selection works continuously to produce new forms and, eventually, new species.

Although this theory of Darwin's showed clearly how natural variation was the basis of evolutionary change, there was no explanation of how the variations occurred or how they were inherited. Later work on genetics, however, has shown how the natural variation can come about and also how sudden changes may lead to the appearance of new characteristics.

Darwin's theory of Natural Selection can explain the evolution of the giraffe's neck quite easily. The early giraffes competed with other animals for food. The giraffes with the longest necks were able to get more food and thus were more likely to survive and produced more offspring. These offspring too had longer necks but, more important, they varied among themselves. Selection again acted in favour of those with the longest necks. Over many generations the average neck length increased until the present-day giraffes appeared.

Several moth species are known to produce occasional black individuals. The gene or genes controlling colour occasionally change so that the black (melanic) form appears. Under normal conditions the black form was easily seen by enemies and was eaten but in the last hundred years or so melanic forms have increased in industrial areas. Smoke pollution has blackened buildings and so the occasional mutation was valuable: the black moth was protected by camouflage and gradually increased its numbers as the black gene was passed on to the offspring. The normal form then declined in these areas. This is a good example of Darwin's idea of changing environment leading to the increase of new forms. The new form was not, however, caused by the changing environment.

NORMAL PEPPERED MOTH

MELANIC PEPPERED MOTH

Genetics and evolution

Every cell in the body has a certain number of minute thread-like structures called chromosomes. For each species there is a fixed number and special processes ensure that each new cell receives its full complement. Each chromosome contains many genes. These seem to be coded messages, written in chemical 'language', that control the development of the features of the whole body. For instance there are genes that control hair-colour, genes that control tooth form, and so on. Sometimes a single gene will be responsible for a feature, sometimes several genes acting together.

During reproduction different combinations of genes are produced. These give rise to variations among the offspring. Sometimes, however, a gene changes radically. Such sudden changes are called gene mutations and they are responsible for the appearance of new characteristics. The vast majority of mutations are harmful – even lethal – because they interfere with the normal running of the body. Occasionally, however, a useful mutation occurs and is favoured by natural selection. It then becomes incorporated in the normal pattern.

What is a Species?

LIFE is present in numerous different forms. This becomes obvious from a glance around the countryside. An elm tree is very different from a holly tree; a rabbit is different from a jackdaw.

In the seventeenth century Linnaeus, the Swedish naturalist, attempted a complete classification of all the known living organisms of his day. By careful inspection and study he recognized a large number of different species. Each species consisted of individuals which were very alike in appearance. These interbred and the offspring produced were very similar to the parents. Thus all lions belong to one species and all polar bears to another.

Today we know that some, if not all, of the structures of organisms are genetically controlled – that is, they depend upon the influence of small particles called genes which are present in the chromosomes of living cells. Members of one of Linnaeus's species are all alike in appearance because the number, structure and arrangement of the chromosomes is similar. Each species keeps its own identity because its chromosomes will not successfully combine with the chromosomes of another species.

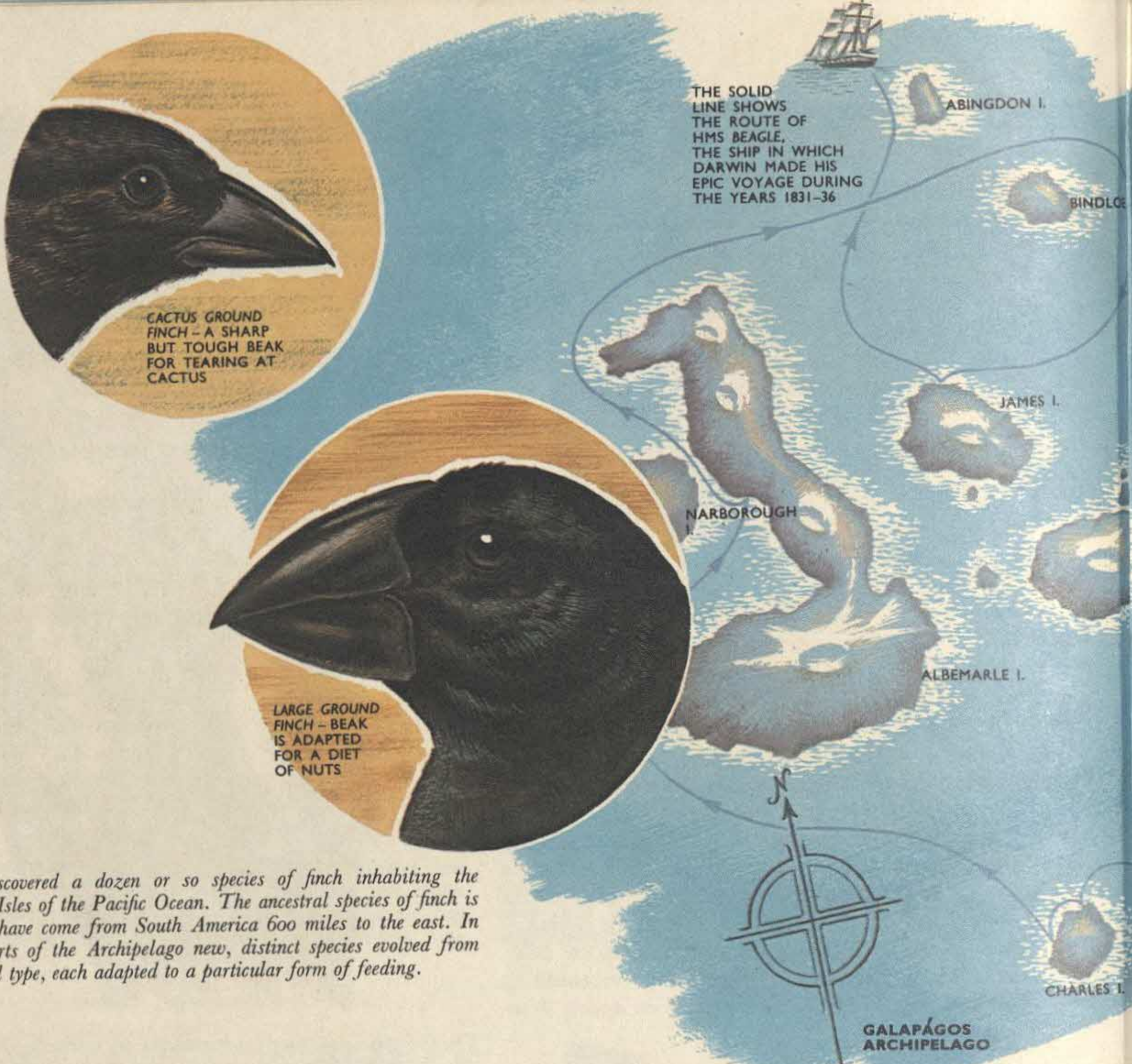
Thus instead of defining a species in terms of its appearance, it can now be defined in terms of genetics. A species is a group whose members will, *in the wild*, interbreed among themselves but will not successfully breed with members of another group for more than one generation.

Evolution and the species

Linnaeus was a Creationist. He considered that all his different groups of individuals (species) were not only separate from one another now, but had always been separate from one another. All species had been created at the same time and none of them had changed since.

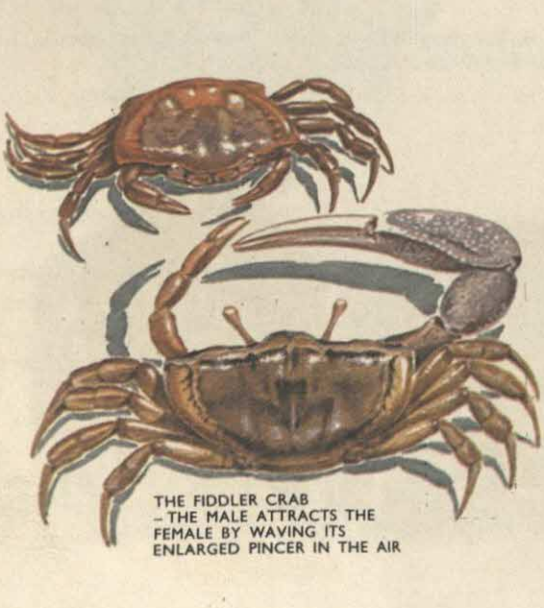
The two species of European tree-creeper are externally indistinguishable, except for their song. At some stage two populations must have been separated long enough for sufficient difference to occur.

Separation between the horse and donkey is not quite complete. Members of the two groups are still able to interbreed but the offspring, a mule or a hinny, are sterile. Horses and donkeys can also cross with zebras; again the hybrids are sterile.



Darwin discovered a dozen or so species of finch inhabiting the Galapagos Isles of the Pacific Ocean. The ancestral species of finch is believed to have come from South America 600 miles to the east. In different parts of the Archipelago new, distinct species evolved from this original type, each adapted to a particular form of feeding.

The theory of evolution put forward in 1859 by Wallace and Darwin explained things differently. According to the evolutionary theory more complicated organisms evolve gradually from simpler kinds. At some stage therefore one species must evolve into another. How does this take place? Certainly not directly. When two members of the same species interbreed they produce offspring very similar to themselves – not an individual belonging to an entirely new species. When dogs breed they always produce puppies and not kittens. Nor do members of different species cross-



◀ *Peculiar courtship displays often ensure that mating will only take place between members of the same species. If species could interbreed freely, the adaptations of each species to a particular mode of life would quickly be destroyed.*

breed to produce a third species; except for very rare instances, species are incapable of successful interbreeding. A cat cannot breed with a dog to produce something midway between the two.

The evolutionary process takes place over a very long time. Members of the same species may become separated by geographical barriers – rivers, mountains, seas. Two distinct populations or more are set up, each population, by natural selection, becoming adapted to the slightly different conditions in its own area. In this way races are formed. One race is slightly different from another, though members of different races can still interbreed and produce offspring. Man – the species *Homo sapiens* – illustrates race formation very well. All over the world are populations of men that have their own distinctive features – Negroes, Bushmen, Mongols, and so on.

The longer a race remains separated from other races of the same species, the more it is likely to diverge in appearance and in its genetical make-up. Finally a stage is reached when the race becomes so divergent with the other races that it can no longer interbreed with them. It is then a new species.

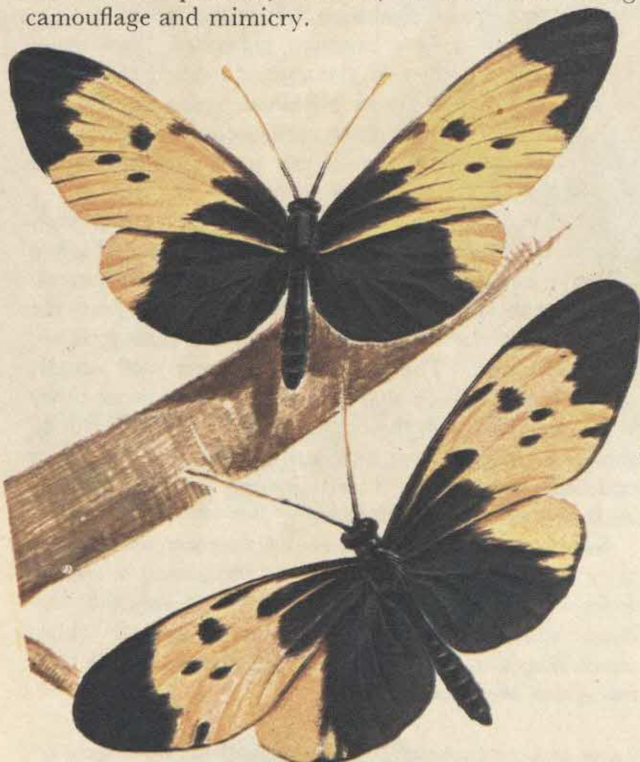
Between race and species there may be a very narrow borderline. A situation may be reached when a degree of interbreeding is still possible between members of two populations. Total isolation, where the two populations are incapable of interbreeding, is not quite reached. The offspring, however, are usually themselves sterile or they are abnormal in some other way. An example is the horse and the donkey. Though these two animals are obviously separate forms, they can still interbreed. The offspring, a mule, cannot itself reproduce – it is sterile.

Such borderline cases are not uncommon; and though they are troublesome in exactly separating a species from a race, they nevertheless provide valuable evidence that the process of evolution is working. They mark stages in the formation of a species which have not quite been completed.

Linnaeus was an Europiform. *In different parts of the world other races have become distinguished. Given long enough races no longer interbreed. They are then true species.*

Imitation in nature

There are over one-and-a-half million different kinds of living animal. Many of these kinds number thousands of millions of individuals. It is, therefore, hardly surprising that there is a great deal of competition among animals; there is truly a 'struggle for existence'. This great competition has led to every conceivable form of defence and attack. Speed, armour plating, warning coloration and foul smell are often used as survival means. Some of the most interesting and remarkable adaptations, however, are those concerning camouflage and mimicry.



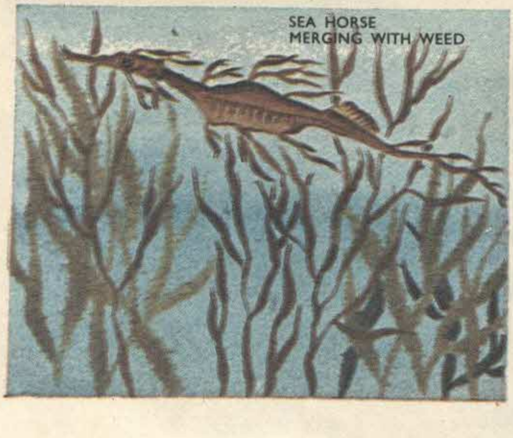
Camouflage involves the resemblance of the animal to its surroundings so that it is inconspicuous to its predators, and, indeed, to its prey. Some of the best examples are to be found among the insects. Many butterflies, although they may be brightly coloured on the upper side, resemble leaves when at rest. Stick-insects and leaf-insects are other well-known examples. Several species of tree-hopper are almost indistinguishable from thorns when sitting on the appropriate twigs and various caterpillars resemble twigs themselves. Some sea-horses are disguised so well that they completely disappear against a background of seaweed.

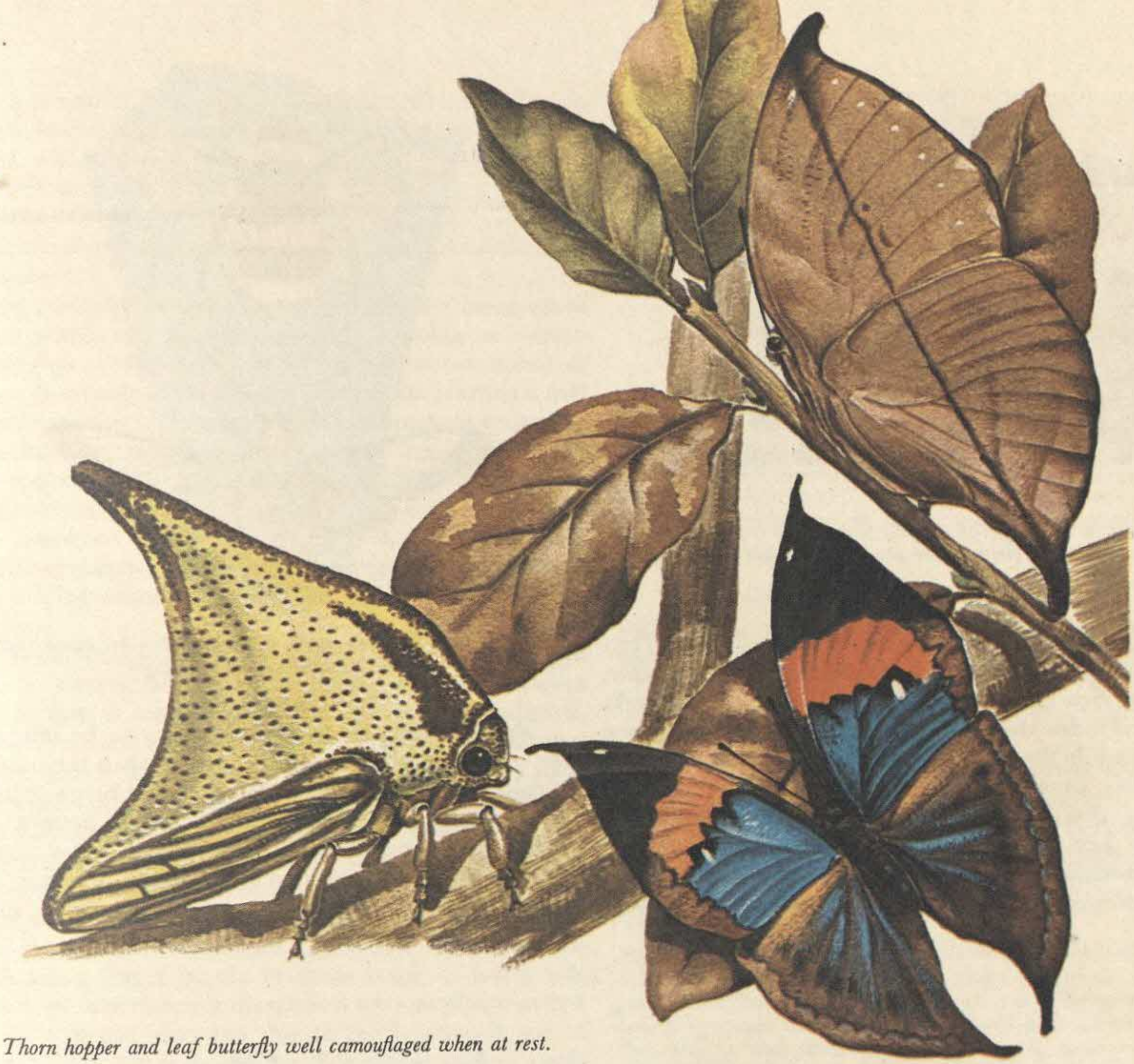
It must not be thought that these animals copy their surroundings in order to merge with them. The resemblances must have been there to start with and the Theory of Natural Selection can be used to explain the close similarities. Individual animals vary a lot and some would have resembled the surroundings more than others. The better camouflaged ones thus stood more chance of surviving and, if the characters which camouflaged them were inherited, their offspring, too, resembled the surroundings. Gradually the present form was obtained for all the individuals.

These two butterflies are both distasteful to birds and benefit by sharing a similar colour pattern. This is Mullerian mimicry.

Bees and wasps are mimicked by many insects. The drone fly (right) is a true fly but, when feeding from flowers, it looks very much like a bee.

Some species of sea horse have long outgrowths and so merge with the seaweed.





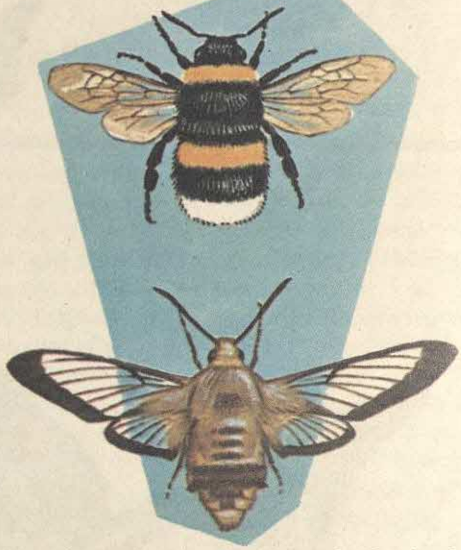
Thorn hopper and leaf butterfly well camouflaged when at rest.

Mimicry is the name given to the cases where an animal derives benefit from resembling another animal rather than its surroundings. It is a special case of protective coloration and can be explained by the Theory of Natural Selection. Among so many species of insect it is not unreasonable to assume that a number of them will look alike, and if one species is protected by evil smell, sting or warning colours, other similar-looking ones will also derive benefit. The resemblance will then be continued and improved by natural selection over many generations.

In 1861 a naturalist named H. W. Bates was travelling along the Amazon and observed that large numbers of black and brown butterflies were congregating despite the presence of many insect-eating birds and other animals. The butterflies were protected by having a distasteful flavour but occasionally there appeared specimens of a very different kind. They looked like the common ones but lacked the distasteful flavour. Bates realised that the edible species were protected from enemies by virtue of their resemblance to the other butterflies and that here was an example of mimicry. This type of example, where a harmless species imitates a harmful one, is known as Batesian mimicry.

The animals that are 'copied' are called the models and the others the mimics. Predators soon learn that certain types of insect or certain colour patterns are associated with stings or vile taste and they leave all such insects alone. The mimic thus gains protection. Even if only one per cent of the mimics are saved, there is a great advantage. The model and mimic must

The behaviour of the spider and the way that it holds its front legs out in the manner of feelers, allow it to mingle safely with ants.



A good Batesian mimic is the harmless bee hawk (bottom) which greatly resembles a bumblebee when in flight.

obviously live in the same areas and mix freely. They must also behave in a similar fashion. For example, many spiders mimic ants. The spiders have dark marks on their sides that give the appearance of a narrow thorax while the front legs are held out rigidly in front as if they were antennae. All this would be useless if it were not accompanied by the correct behaviour, and so they dash to and fro in the urgent manner of ants, mingling with them so well that even trained entomologists have captured them thinking they were ants.

Obviously for this type of mimicry to be effective, the models must be much commoner than the mimics. If this were not so, the predators would be quite likely to associate good food with the colour pattern and both mimic and model would decline. The way in which the size of the two populations – mimic and model – is controlled is an especially interesting problem.

Insects that resist insecticides —an interesting example of evolution

When D.D.T. and other powerful insect-killing compounds were introduced in the 1940's, the goal of complete eradication of insect pests came into sight. These new insecticides were active against a wide range of insects at doses low enough, in most cases, to be harmless to Man and other animals. Widespread use of D.D.T. and other compounds produced amazing results but this happy state of affairs was not to continue. After a few years it was noticed that larger doses were necessary to kill the insects. The size of the required dose increased gradually until it reached danger level for other animals or until the cost of insecticide exceeded the value of controlling the pests. Use of the insecticide then had to stop. The insects had become *resistant* to it.

When an insect had become resistant to one type of insecticide it was sometimes possible to control it with another compound, but resistance frequently developed to the second insecticide. Quite often resistance to one insecticide made the insect automatically resistant to another one. Resistance to insecticides was first discovered in the common housefly in 1946. Later, malaria-carrying mosquitoes were found to be resistant to D.D.T. At the present time more than one hundred insect species are known to contain individuals which can resist insecticides and the insecticides concerned are of all types.

There are two main ways of attacking resistance. One is to look continually for new insecticidal compounds to replace those that have lost their effectiveness

and the other is to attack the resistance itself. Finding new insecticides is only a short-term policy, for they, too, will probably meet resistance later. Some of the newer insecticides are already causing alarm because of the effect on animals other than insects. The real answer to resistance is to attack the actual mechanism involved.

A great deal of time and money is now being spent on research into insect resistance. By using an insecticide that contains radioactive carbon atoms, scientists have been able to follow what happens to it when it gets inside an insect. In one of the most important resistance mechanisms yet discovered, insects break down the poisons into relatively harmless substances. This is done by various enzymes in the body. It may be possible to overcome resistance by preventing the action of these enzymes. This is done already to some extent by adding other substances (synergists) to the insecticides.

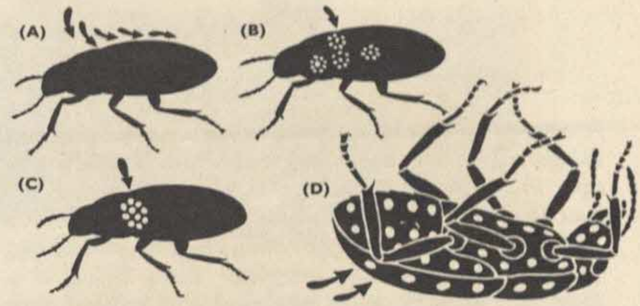
At one time it was thought that continuous exposure to low concentrations of insecticides caused resistance to develop in insects. This idea has been abandoned, however, for it appears that in any natural population some insects will be slightly resistant. These resistant insects have more chance of surviving an application of insecticide and, providing resistance is inherited, the population will gradually come to contain more and more resistant insects. Some will be more resistant than others and the continued application of insecticide will eliminate all but the most resistant. They will then reproduce and a highly resistant strain of insect will develop. Resistance is therefore a natural phenomenon and its spread has been due to the large-scale use of insecticides. It may well be that future control measures will depend on biological methods and so avoid the whole problem of resistance. But in the meantime the fight against resistance must go on.

Resistant insects which arise in this way have now a new characteristic which was not evident in the original population. They have evolved. The essential steps in the process are:

1. *Variation* – at some point resistance to D.D.T. developed in a small proportion of the population. It is not known how such a change – non-resistant to resistant – took place. It may be that some rare oddity of development which had always occurred in a few flies happened to confer resistance to D.D.T. when it was applied.

2. *Selection* – when D.D.T. is applied resistant flies survive; non-resistant flies die. Not all non-resistant flies die at once but the survival rate of resistant flies will be greater than the survival rate of non-resistant flies.

3. *The character* – resistant – *is inherited.* This *may* mean that the character is produced by a gene carried



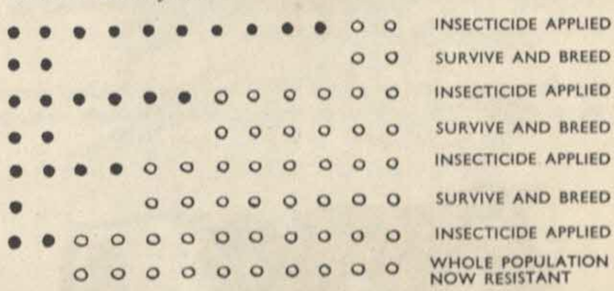
Diagrams to show three possible mechanisms of resistance. (A) The insecticide cannot pass through the cuticle. (B) It is destroyed as soon as it gets into the insect. (C) It is stored in some tissue and cannot act. (D) A susceptible insect in which insecticide has spread and had effect.

on a chromosome. (It could be carried in the egg protoplasm, in which case the pattern of its inheritance would be different.)

It follows that the offspring of resistant flies will contain a higher proportion of resistant flies than the offspring of non-resistant flies.

In the course of a number of generations, depending on the severity of selection and the pattern of inheritance, the character – resistant – will become more common than non-resistant. The flies will have evolved a new character.

Any natural population has a few resistant individuals (solid blobs). When insecticide is applied, these resistant individuals survive together with a few susceptible ones (circles). The following generations have progressively more resistant individuals until all are resistant. Resistance has been found in the colorado beetle, mosquito, housefly, cockroach and body louse.



COLORADO BEETLE

Examples of adaptation

ADAPTATION is a very important feature in living things. The parts of animals and plants have a structure which makes them especially suited for the job that they perform. For example, feet are put to a variety of uses: swimming, running, digging, scratching, perching, grasping and jumping. Birds living in a particular situation on a particular kind of food have feet that are highly efficient in the tasks that they usually perform. They are *adapted* to their job. They often appear to be so well 'designed' that it is difficult to believe that chance variation and mechanical selection could account for adaptation. The evolutionary argument may be stated as follows.

The basic pattern of a bird's foot, once established, varied in small details from one bird to another. The relative size of bones and claws and the relative development of webbing was not uniform throughout the range of birds.

Food preferences, nesting and mating habits and changing circumstances in their surroundings would decide that some birds would favour one kind of situation rather than another, say a river rather than an open plain. As soon as a population becomes divided up in this way then the process of evolution will follow an even more diverse path. The selection pressures will differ in different environments. Thus, if swimming is necessary for survival, any bird with more webbing than average will be that much more efficient and more likely to survive than its fellows. Providing the webbing character is inherited by its offspring then the way is clear for an increase in web-footedness in the river birds.

On the other hand birds which favoured open plains might have been selected for their ability to run, so that any variation towards increased leg length and slenderness of toe would, providing it was inherited, lead to an evolution in this direction.

Man as a selection agent

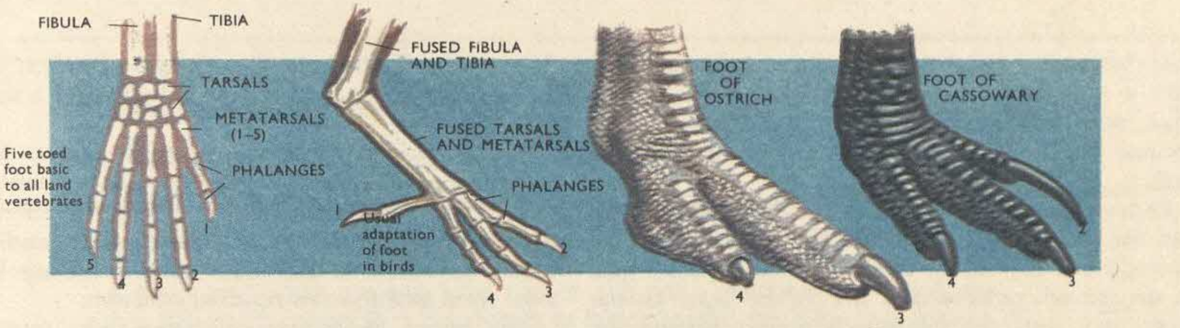
One startling aspect of evolution is the rapid, often grotesque changes that are produced when Man selects from a wild population according to his likings. Fancy breeds of dogs, mice and birds are badly adapted for survival 'in the wild'. Man has selected artificially – much more efficiently than natural predators – and has produced a rapid evolution in those animals chosen for domestication.

The feet of birds

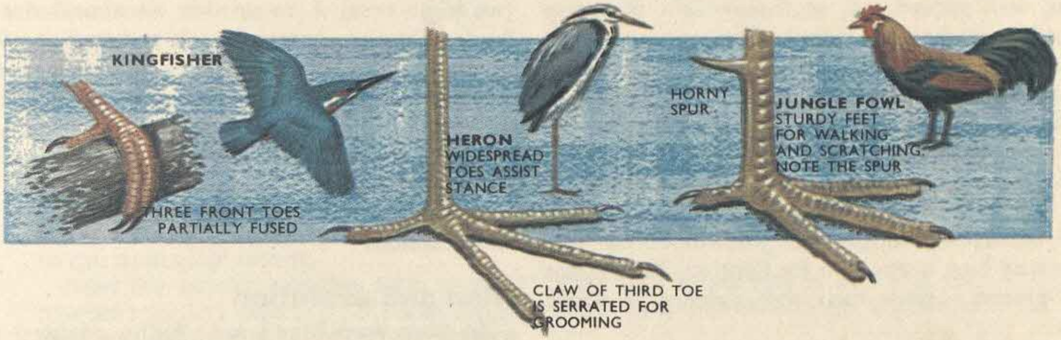
A foot with five toes is basic to all land vertebrates. But most birds have feet with four toes; the fifth has gone without trace. The first (big) toe, called the *hallux*, is usually turned towards the rear. Working in opposition to the other three, it provides an excellent mechanism for perching or – in the case of flesh-eating birds – for grasping and carrying prey. Alternatively, the backward-pointing hallux may be very long and straight as in larks and wagtails. These birds spend a lot of time running over flat ground and the long hallux helps their stance.

The large flightless birds, in the majority of cases (e.g. cassowary), have lost their first toes. They do not need a perching foot of any kind. The 8 ft. tall ostrich, largest of living birds, has not only lost the first toe

The Friesian cow, bred for its milk yield, is common in lowland pastures. Tougher and more hardy is the Welsh Black, bred to thrive in mountainous districts. The latter are kept mainly for meat but they are reasonably good milkers giving fair yields under poor conditions.



(from left to right) The typical five-fingered foot of a land vertebrate, that of a typical bird, the two-toed condition of the ostrich – and the three-toed condition of the cassowary.



but the second as well. It runs using the third and fourth toes.

In woodpeckers, cuckoos, parrots and toucans the fourth toe, as well as the first, may be turned backwards. The result is a strong, stable climbing and perching mechanism which can also be used for feeding purposes. One family of birds, the trogons, also has two toes facing forwards and two backwards. But it is the second toe that has moved to the back, not the fourth.

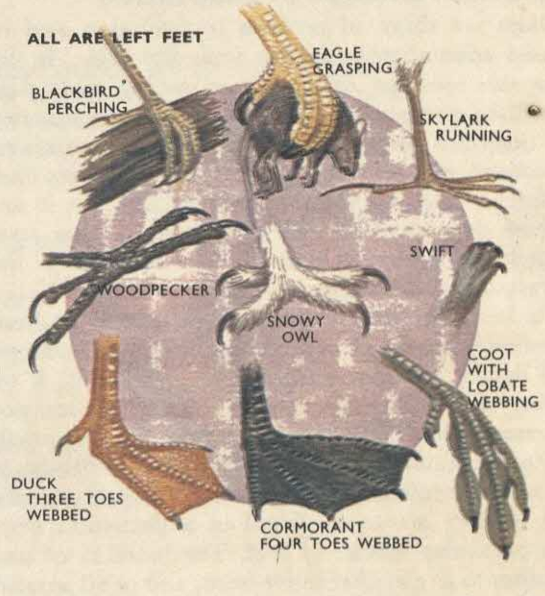
Owls, rollers and the osprey have a flexible fourth toe which, though normally facing forwards, can also be turned backwards. In contrast, swifts have a flexible toe which can be moved forwards. Using their four forward-projecting toes, they hang from small projections; their feet are too feeble for normal perching.

Occasionally toes are fused for some of their length. Kingfishers, motmots and the West Indian todies all have three front toes partially joined; a scoop-like structure is formed, excellent for digging nests in the ground.

Water birds engaged in swimming and diving may have flaps of skin between the toes, forming a webbed foot. The webbed feet act as paddles, presenting a large, 'oar-like' surface area to push against the water. They may also be used for steering.

Usually only the front three toes are webbed and the hind toe (i.e. the first toe) is reduced in size as in ducks and geese. But some web-footed birds – cormorants and pelicans for instance – have the first toe brought into a forward position and it, too, is webbed.

Birds with webbed feet are ungainly and clumsy walkers on land. Coots, grebes and phalaropes – also



(at top) The three forward toes and one rear toe provide mechanisms for perching, grasping or running. (middle) In the woodpecker and other birds the second toe points backwards as well as the first. The owl can if necessary rotate its second toe backwards; the swift in contrast can rotate its first toe forward. (below) Webbing of feet in duck, cormorant and coot.

water birds – have each of the three front toes provided with a scalloped fringe of skin instead of a web. This extra surface area facilitates swimming, but, because each toe is free, the birds can walk easily as well.

Perhaps the best swimmers of all are the divers and the grebes. The diver's webbed and the grebe's lobate limbs are set far back on their bodies – just as the propellers of a boat are at the rear. In the diver, it is only the feet which project beyond the body. Leg bones above the ankle are encased within.

Birds which walk over soft mud-flats tend to have long toes, well spread out, so that weight is evenly distributed, e.g. heron, curlew. The jacanas have particularly long toes and walk unconcernedly over floating leaves.

Chicken and game-birds spend a lot of time on the ground scratching about for food. Their feet are sturdy with three strong toes in front; the hind toe usually remains small. The toes have blunt claws used for scratching the ground; just above the first toe there may be a horny spur for fighting. Ptarmigans – arctic grouse – have their toes covered in warm feathers.

The claw of the third (middle) toe of a few birds – herons, owls, bitterns and nightjars – has a comb-like serrated edge used for grooming and removing slime from feathers.

The disadvantages of adaptation

Often we think of progress in evolution and increased adaptation as if they were the same. In one sense this must be correct. It is, at the same time, true that increased adaptation can lead to extinction. An organism well adapted to one particular environment will be very efficient in extracting from its surroundings its requirements for life, but it may become dependent on the environment being static – unchanging. Specialisation often leads to a lack of variability. Consider a parasite living in the gut of its host. It can withstand the action of its host's digestive enzymes; it can remain attached to the gut wall despite the forces tending to dislodge it; it can extract oxygen from its surroundings which are poor in oxygen; it can return to its host after a usually very complicated life history – it is in brief well adapted to its environment. Parasites are often very specific; that is, they are to be found in a particular organ in a particular species of host. The inability of some parasites to live in alternative hosts, and of all parasites to complete their life histories outside hosts, means dependence. If the host dies, the parasite dies; if the host becomes extinct, the parasite will suffer a similar fate.

The earliest amphibians were inefficient fishes. Their lobe fins were ill-adapted to the functions carried out by typical fish fins. The variability of such fins was such that, given the climatic conditions which prevailed in Devonian times, walking limbs arose from lobe fins as a result of selection.

The larger herbivorous dinosaurs may have depended on the numerous lakes or similar masses of water: *a.* to support some of their considerable weight (up to 50 tons), *b.* to provide an abundance of plant food. Climatic changes which reduced the frequency of such large masses of water probably contributed to their extinction: *a.* because they were incapable of supporting their weight out of water for long periods, *b.* because the plants on which they lived were less plentiful.

Adaptation leads to specialisation which is one path to extinction.

Man and evolution

In many ways Man is not a highly adapted organism. His arms and legs are not as highly evolved as those of horses, for example. Man is found in large numbers over most of the earth's surface; he can support himself for considerable periods in the sea, and for short periods in space above the earth's atmosphere. Man's success depends on his ability to control his environment – his food supplies, the temperature of his surroundings, the atmospheric pressure of his surroundings and disease-causing organisms; Man selects rather than is selected by his environment.

Evolution may be likened to a main stem with side branches. Each side branch represents increased adaptation, increased specialisation. The main stem consists of those changes in living organisms which have led to increasing independence of environment by an increase in the ability to control – to control water content, to control mineral salt content of blood, to control temperature, to control oxygen uptake, and to control the activities of other organisms.

Man seems to be nearing a position in which he can control his own evolution. Already, selection by changing environmental conditions, which seems to have been an important mechanism in evolution, no longer applies. Soon Man may be able to decide how he is going to vary. Future generations will be faced with weighty decisions on how to use the powers which science has placed at their command.

A discussion of problems on page 25

No. 1

The black and white, black and white cross yielded 5 black and white offspring and 2 white offspring.

We know, therefore, that at least one parent was carrying the factor for white coat colour. As neither parent was white, the factor for white must be recessive to the factor for black and white, which is dominant.

A black and white rat may have one of two gene arrangements (genotypes), either BB or Bb, where B is the dominant factor (gene) causing development of black and white coat colour and b is the recessive gene causing white coat colour.

This mating might have been;	BB	X	BB 1	
	or Bb	X	Bb 2	
	or BB	X	Bb 3	

Because 2/7ths of the offspring were white (1) cannot be correct. How can we distinguish between (2) and (3)?

The cross Bb X Bb would give black and white rats and white rats in the ratio of 3 : 1.

The cross BB X Bb would give black and white rats and white rats in the ratio of 1 : 1.

We cannot tell whether the male or female parent carried the factor for whiteness into the cross from the evidence given. In either case it would make no difference to the numerical results.

Now the nearest possible ratio to a 1 : 1 ratio with seven rats is 3 : 4 and the nearest to a 3 : 1 ratio is 5 : 2. However, with such small numbers it is impossible to decide if statements (a) or (d) are correct.

If we examine each statement: (a) If the female had previously been mated with a white male, we may picture the event thus:

	Bb X bb	or	BB X bb
Offspring:	BB : bb		ALL Bb and therefore all black and white.
Ratios:	1 : 1		
For seven offspring	4 : 3 or 3 : 4		

The chances of a Bb combination and a bb combination are at each fertilization 50 : 50. Only *one* combination has to go 'the wrong way' to give a 5 : 2 ratio. This could easily happen in the same way that if you spin a penny seven times even though the chances are 50 : 50 for heads and tails 5 : 2 ratios will not be uncommon.

For this reason we cannot distinguish between explanation (a) and (d).

No. 2

The ratio, 36 black and white to 14 white, can be compared with:

a. 1 : 1 ratio i.e. 25 : 25

b. 3 : 1 ratio i.e. 39 : 13 approximately.

The similarity between the results given and a 3 : 1 ratio indicates that in problem No. 1 statement (d) must be correct. The parent rats must both have carried the gene for whiteness.

No. 3

A white rat must have the genotype bb because the white factor is recessive to the black and white factor. (See previous problem.)

A black and white rat from a black and white, black and white cross, may have either genotype BB or Bb.

The offspring from a

bb X BB or Bb cross

were ALL black and white. Therefore the black and white parent must have had the genotype BB. The offspring must all have had the genotype Bb. This condition is described as heterozygous.

No. 4

The black and white rats from the cross in problem No. 3 had the constitution Bb. On mating such rats, Bb X Bb, a 3 black and white to 1 white ratio would be expected. A 3:1 ratio is approximately, 39:13 or 36:12. The nearest ratio given to these is (c) 40 black and white to 10 white.

No. 5

In Drosophila, vestigial winged condition is recessive to the wild type or normal winged type.

Now, normal winged flies may have the genotype Vg+ or ++ (+ being the normal gene: if you wish you may use N for normal and n for vestigial in which case normal winged flies would be either NN or Nn).

Vestigial winged flies must have the constitution, VgVg (or nn).

The cross VgVg X ++ (nn X NN)

would give offspring all of which had the constitution Vg + (Nn).

Now we are told that 10% of the flies were vestigial winged. How could this ratio have been given? If the normal winged parent had not been pure bred but had been heterozygous, i.e. carried both genes, a 1:1 ratio would have been given, thus:

	VgVg X Vg+	(nn X Nn)
Offspring:	VgVg and Vg+	nn and Nn
Ratios:	1 : 1	1 : 1

But, the observed ratio of 9 normal to 1 vestigial winged could not with reasonable probability approximate to a 1:1 ratio. Therefore statement (c) is incorrect. The evidence given does not support statements (a) and (b). If (a) were true all the offspring would be normal. If statement (b) were true either wings of the offspring would be of intermediate form or alternatively all might be vestigial winged.

If when the cross was set up one of the female vestigial winged flies was not virgin, i.e. it had previously mated with a vestigial winged male, this would account for the presence of vestigial winged flies, in a ratio which we cannot explain in any other way.

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